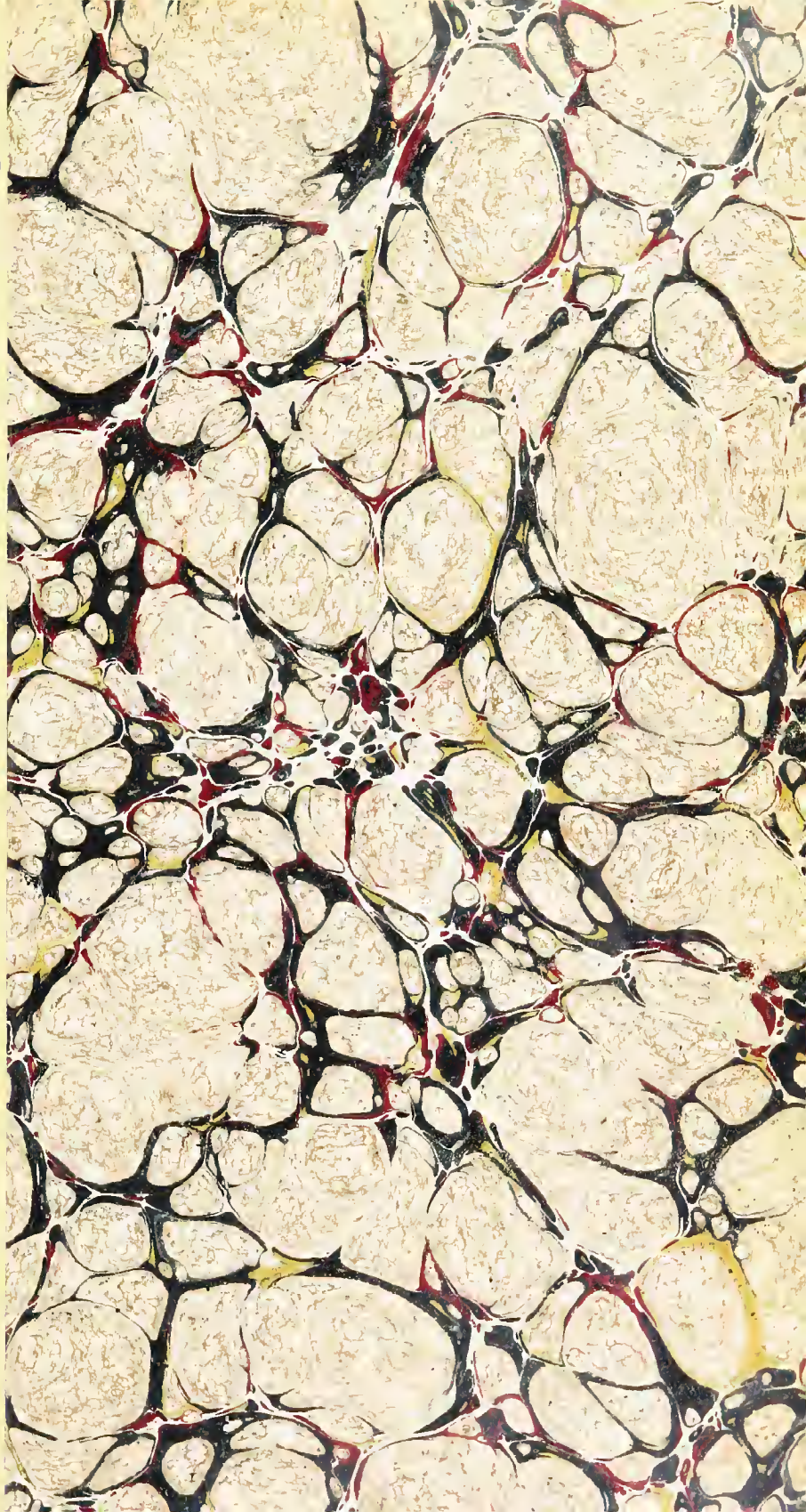


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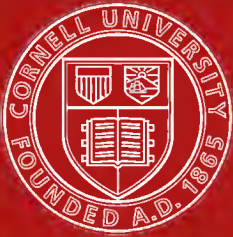
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MEMOIRS OF THE GEOLOGICAL SURVEY.

ENGLAND AND WALES.

EXPLANATION OF THE NOTTINGHAM DISTRICT
SHEET.

THE GEOLOGY OF THE COUNTRY AROUND NOTTINGHAM.

BY

G. W. LAMPLUGH, F.R.S., AND W. GIBSON, D.Sc.

PUBLISHED BY ORDER OF THE LORDS COMMISSIONERS OF HIS MAJESTY'S TREASURY.



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Plate I.
(*Fruitpiece.*)

Geology of Nottingham.



THE TRENT VALLEY AT NOTTINGHAM DURING THE FLOOD OF OCTOBER 22ND, 1875.
From a photograph taken from the terrace of Nottingham Castle, looking south.

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PREFACE.

The map of the area described in this Memoir has been prepared by combining portions of four of the numbered New Series sheets, previously issued by the Geological Survey, in such a manner that the city of Nottingham lies nearly in the middle of the new sheet, which is of the usual size. This has been done mainly for the benefit of students.

Of the four sheets laid under contribution, the largest portion is taken from Sheet 126 (published in 1908); not quite so much from Sheet 125 (published in 1908), and relatively small portions from Sheets 141 (published in 1904) and 142 (published in 1909). The field-work on which the new Nottingham District Map is based was done by the following officers: the late C. Fox-Strangways, Dr. W. Gibson, Mr. R. L. Sherlock, Mr. W. B. Wright, Mr. B. Smith, Mr. S. B. Wilkinson, and Mr. G. W. Lamplugh; their respective shares in the survey are shown in the table of 6-inch maps on the next page.

The present memoir is largely compiled from the previous memoirs accompanying the above-mentioned serial sheets. The second chapter, dealing with the Carboniferous rocks, is entirely the work of Dr. Gibson, who surveyed the whole of the Coal Measures shown on the Map; the remainder of the volume has been written or compiled by Mr. Lamplugh, who has also acted as editor.

In preparing this memoir the customary procedure has not been followed. The full local details having been already made available in the previous memoirs, a more general treatment of the subject has been attempted. Only so much local detail, therefore, is now given as will serve generally to illustrate the composition of the different formations; and a wider latitude than usual is allowed to the discussion of conditions of deposition and other allied problems arising from the geological structure of the district. A chapter is also added at the end of the memoir, entirely for the use of students, in which the educational features of the local geology are recapitulated *seriatim*. References to most of the published papers relating to the district will be found in the foot-notes. Separate bibliographies have appeared in the memoirs on Sheets 126 and 142.

We are indebted to Dr. F. J. Allen for the photograph reproduced in Plate II. Plate I. is from a print in my possession, and the remainder are from photographs taken for the Survey by Mr. T. C. Hall.

We have again to thank Prof. J. W. Carr for his courteous assistance in many ways during the preparation of the work.

J. J. H. TEALL,

Director.

Geological Survey Office,
28, Jermyn Street, London.
16th March, 1910.

LIST OF SIX-INCH MAPS.

The following is a list of the six-inch Geological Maps included in the area, with the names of the surveying officers. MS. coloured copies of these maps are deposited for public reference in the Library of the Geological Survey and Museum of Practical Geology. The quarter-sheets marked with an asterisk have been published with the geological lines engraved, and can be obtained at the price of 1*s.* 6*d.* each uncoloured; also hand-coloured at the extra cost of colouring.

QUARTER-SHEETS.

DERBYSHIRE.

- *40. SE. (part), by W. Gibson.
- *45. NE. (part), *SE. (part), by W. Gibson.
- *46. NW., *SW. (= NOTTS., 37 SW.), by W. Gibson.
- *50. NE. (part), by W. Gibson.
- *50. SE. (part), by C. Fox-Strangways.
- *51. NW. (= NOTTS., 41 NW.), by W. Gibson.
- *51. SW. (= NOTTS., 41 SW.), by C. Fox-Strangways.
- 55. NE. (part), by C. Fox-Strangways.
- 56. NE., NW., SE. (part), SW. (part) (= NOTTS., 45), by C. Fox-Strangways.

NOTTINGHAMSHIRE.

- *32. SE. (part), by W. Gibson and R. L. Sherlock.
- *32. SW. (part) (= DERBY, 41 SW.), by W. Gibson.
- 33. SE. (part), SW. (part), by R. L. Sherlock.
- 34. SE. (part), SW. (part), by G. W. Lamplugh and S. B. Wilkinson.
- *37. NE., *SE., by W. Gibson.
- 38. NE., NW., SE., SW., by R. L. Sherlock.
- 39. NE. (part), SE. (part), SW., by G. W. Lamplugh and W. B. Wright.
- 39. NW., by G. W. Lamplugh.
- *41. NE., by W. Gibson.
- *41. SE., by C. Fox-Strangways.
- 42. NE., NW., SE., SW., by R. L. Sherlock.
- 43. NE. (part), SE. (part), SW., by W. B. Wright.
- 43. NW., by W. B. Wright and R. L. Sherlock.
- 46. NE., NW., by R. L. Sherlock.
- 47. NE. (part), NW., SE. (part), SW. (part), by B. Smith.

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THE GEOLOGY OF THE COUNTRY AROUND NOTTINGHAM.

CHAPTER I.

PHYSICAL FEATURES AND GEOLOGICAL STRUCTURE.

AREA.

The map, being a special sheet, and not one of the numbered series, has been so arranged that the city of Nottingham lies in the middle of the sheet. Being of the standard size, *i.e.*, 18 inches by 12 inches, it embraces the country eastward and westward for about 9 miles from the centre of the city, and northward and southward for 6 miles from the same point. The area is shown on the sketch-map, Fig. 1, p. 2, on which the chief places and features are diagrammatically indicated. East of the meridian of Nottingham, the country is almost wholly agricultural, with a relatively sparse population, save in the growing villages which are practically the eastern suburbs of the city. West of the same meridian the country is densely inhabited by an industrial population clustered around numerous centres of coal-mining and manufacture of various kinds.

DRAINAGE.

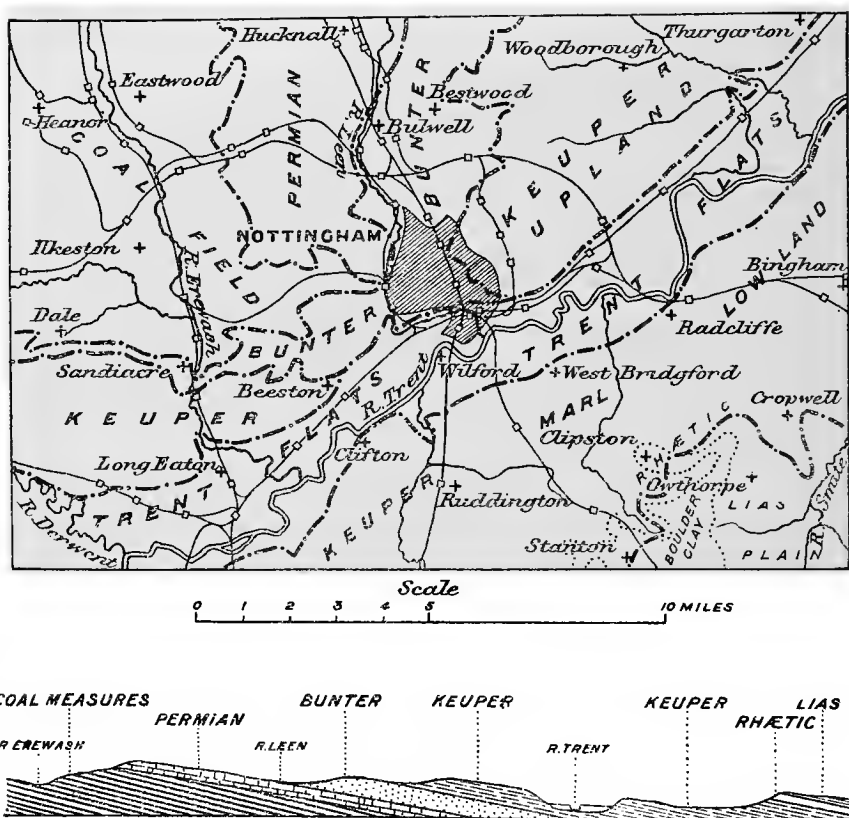
The course of the River Trent runs obliquely across the map from the south-western to the north-eastern corner, and the whole area lies within the basin of this fine river, whose broad trench with its floor of alluvium and ancient flood-gravels forms one of the most conspicuous features of the map, both geologically and physiographically. Except at one point where it just touches the Bunter, this trench keeps curiously within the Keuper formation, and, in general terms, it may be classed as a longitudinal or strike-valley. With the aid of two short artificial cuts, the Trent has been rendered navigable for barges from its mouth up to Nottingham; and, by longer supplementary canals, its higher reaches are similarly utilised.

In the broad alluvial tract occupying the south-western corner of the sheet, the Trent is joined by two important tributaries—the Derwent, flowing from the north-west, and the Soar, from the south-east; but the valleys of both streams lie outside the map. The tributaries next in consequence are the Erewash and the Leen, both flowing from the north, and having the main portion of their basins within the map in very definite relationship to the geological structure, as hereafter explained. The remaining tributaries of the Trent in the district are relatively unimportant, and need no particular mention here.

SHAPE AND GEOLOGICAL STRUCTURE.

Since the shape of the ground in this district is, as usual, directly dependent upon the character of the underlying rocks, we may combine a general introduction to the geology of the area with the description of its surface-features, dealing with the rock-formations and their surface-expression in ascending geological sequence. The dip of the strata as a whole is toward the south-east; therefore the oldest 'solid' formation emerges in the north-western part of area, while the newest is confined to the south-eastern part.

FIG. 1.—SKETCH-MAP OF THE NOTTINGHAM DISTRICT, WITH DIAGRAMMATIC SECTION.



CARBONIFEROUS.—The Carboniferous rocks occupy about 35 square miles in the north-western portion of the map, and consist almost entirely of the Middle and Lower Coal Measures. The highest sandstone of the Millstone Grit Series, underlying the Coal Measures, emerges for a short distance along the southern rim of the Carboniferous tract under circumstances of peculiar interest (p. 11), but its usually bold features are partly masked and confused by those of the overlapping Triassic rocks.

The Coal Measures are composed of dark shales, alternating with thin bands of flaggy sandstone and occasional coal-seams ; the total thickness of these rocks contained in their actual outcrop in the district is about 2,500 ft. They perish readily under the weather, and form an undulating low country which coincides very closely with the basin of the Erewash River. The undulations in this tract generally mark the outcrop of the sandstone bands among the softer shales.

The ground slopes as a whole toward the south-east, and it is noteworthy that the same slope is continued beneath the Permian and Triassic cover, the present surface of the Carboniferous rocks in Nottinghamshire being merely the tilted and re-eroded platform on which the newer rocks were deposited (p. 21). Near the north-west edge of the map the outcrop of the Coal Measures rises to slightly above the 400-ft. contour, but where it passes under the newer rocks along the southern margin of the coalfield it is frequently below 150 ft. O.D. The Erewash River occupies a longitudinal or strike-valley so far as the Coal Measures are concerned, but breaks transversely through the high confining rim of Triassic rocks on the south, cutting a well-defined notch across their strike at Stapleford and Sandiacre, by which the stream gains access to the Trent flats.

PERMIAN.—After the deposition of the Coal Measures there followed a time during which the Carboniferous rocks were uplifted, thrown into shallow folds, broken by faults, and then worn deeply down by erosion till a nearly plane surface was produced upon which the Permian and Triassic deposits were afterwards overspread. The earliest of these newer deposits in the district was the Magnesian Limestone, a marine formation of peculiar character.

The present outcrop of the Magnesian Limestone runs uninterruptedly from the coast of Durham southward to the neighbourhood of Nottingham, in its course passing across the edges of the now widely-separated coal-basins of Durham and Yorkshire. Attaining its greatest thickness and importance in the north, the limestone becomes attenuated southward and reaches its termination near the western suburbs of Nottingham. Where it enters the area of our map it has a thickness of 40 to 50 ft. and a breadth of outcrop measuring 3 miles. Here it rises in a sharp bank-like escarpment above the lower country of the Coal Measures, and its whole outcrop forms a broad shelf declining slightly toward the east in accordance with the dip of its strata ; but as it thins down toward its southern termination these surface-features become enfeebled until they are hardly recognizable.

Above the Magnesian Limestone comes the Permian Marl, consisting of 10 to 20 ft. of red shaly clay or 'marl,' with thin hard sandy bands. This division also disappears southward, apparently not continuing quite so far as the limestone. Being 'weak' in weather-resisting properties, the Permian Marl has been hollowed out along its outcrop, thus producing the broad shallow strike-valley of the River Leen, flanked on one side by the gentle dip-slope of the Magnesian Limestone and on the other by the bold escarpment of the Bunter.

TRIAS.—In superficial extent, the Trias is the predominant rock-system of the map, overspreading nearly two-thirds of its area. The system is separated into two major divisions of different composition, the lower or Bunter formation consisting mainly of sands, soft sandstones and pebbly beds; and the upper or Keuper, mainly of red clays or marls with some subordinate sandy beds. Each division is further subdivided into two portions by slighter differences of material. There is also, above the Keuper, a thin series of deposits, known as the Rhætic, which it is customary to class with the Trias. These divisions and subdivisions have all impressed their individuality upon the surface-features of the country in varying degree according to their powers of endurance.

BUNTER.—The semi-coherent pale buff or reddish sandstones and pebbly beds of the Bunter form a belt of dry hummocky country, ranging southward from the neighbourhood of Bestwood (the beginning of the Sherwood Forest of old), where the summits occasionally rise above the 400-ft. contour, to the city of Nottingham where they sink below 200 ft. Thence, with a sudden change of strike—due in part to faulting—the outcrop is prolonged westward in a narrowing strip overlooking the low southern edge of the coal-field, the Bunter here resting directly upon the lowest beds of the Carboniferous outcrop, so that the unconformity or gap in the sequence becomes greater than in any other part of the map.

The Pebble Beds which form the upper subdivision of the Bunter, being somewhat firmer and more coherent than the lower subdivision—the Lower Mottled Sandstone—maintain a generally steep escarpment, cresting the long slopes formed by the latter. Often the Pebble Beds are sufficiently compact to stand in bold crags, of which the crags of Nottingham Castle (Plate V, p. 32) and the pillar of the Hemlock Stone near Bramcote are magnificent examples. Being nevertheless easy to excavate, the Bunter crags in Nottingham have in many places been dug and shaped for various purposes from early times up to the present day.

The Bunter beds have a total thickness of 400 to 450 ft. in the northern district, but become thinner southward. Along the southern edge of the coal-field they show much local variation, having been deposited upon an uneven surface whose inequalities are levelled up by them.

KEUPER.—Though composed for the most part of readily disintegrated strata, the superior thickness of the Keuper and the presence, at intervals, of thin rocky bands known as 'skerry,' have given rise to a bold escarpment at the outer edge of the formation, which is one of the most conspicuous features of the district. The crest of this escarpment at Cockpit Hill near Woodborough, with an elevation of 508 ft. above O.D., is the highest spot within the map. Southward and eastward the crest declines to 300 ft. or less as it approaches the Trent valley, while south of the Trent the surface of the Keuper is mainly below the 200-ft. contour. The lower part of the formation, constituting the Waterstones subdivision, consists of thin flaggy alternations of soft loamy sandstone and marl, usually brown, deep red or greenish-grey in colour, and having a thickness of 80 to 100 ft. These beds are sharply marked off from the underlying Bunter by their colour, thin and regular bedding and

loamy texture ; but they have no definite upper boundary, being distinguishable from the overlying Marl only by the number and softness of their sandy bands. The Waterstones form the long concave slope of the Keuper escarpment, while the Marl with its skerry bands makes a steeper rise toward the crest.

The Keuper Marl is a well-stratified green-streaked red calcareous clay or fine silt, which was probably accumulated in the quiet waters of an inland sea or salt lake. It attains an average thickness of about 700 ft., and dips south-eastward at a low angle, generally less than 3 degrees.

Its skerry bands, though not often more than a foot or two in thickness, by their superior hardness uphold little plateaux on the escarpment and between the minor valleys, well exemplified by the Mapperley Plains near Nottingham. These flat-topped hills and the intervening trench-like valleys or 'dumbles' are especially characteristic of the Keuper upland north-east of Nottingham, where many small streams have cut into the dip-slope of the formation. South of the Trent and, again, west of Nottingham, these surface-features of the Keuper country are less pronounced, owing partly to the lower drainage-gradients and partly to the overlying patches of drift which protect the Marl and produce irregular undulations.

In the upper part of the Keuper Marl, skerry-bands are rare, while gypsum which occurs locally in the lower beds in small veins and strings becomes much more abundant ; and along this gypsiferous belt a broad hollow is usually developed, holding alluvial flats, *e.g.*, the moors south of Ruddington, and east of Cropwell Bishop.

RHÆTIC.—In its mode of origin and its stratigraphical relations, the Rhætic is more closely allied to the overlying Lias than to the Trias with which it is now classed. It is a marine deposit, consisting of black shale in the lower part, overlain by grey shale and clay with nodules and impersistent layers of hard brittle limestone. The thickness of the whole series is only about 30 ft. in Nottinghamshire. Its outcrop is confined to the low but very definite escarpment which it supports, with the aid of the limestone bands of the Lower Lias, at the south-eastern corner of the map. Near Clipston and Stanton, however, this feature is buried under drift. The crest of the escarpment is above the 200-ft. contour west of Owthorpe, but sinks nearly to the 100-ft. contour eastward where it leaves the map.

LOWER LIAS.—The tract of about 12 square miles lying within the escarpment just mentioned is underlain by greyish-blue shales, interstratified with flaggy clay-limestone or cement-stones, which form part of the Lower Lias. The greater part of the area is low and almost featureless, save for slight undulations marking the outcrop of the thin limestone bands among the softer shales. This low ground is bounded on the west by a steep rise marking the edge of the overlapping sheet of boulder-clay which forms the higher tract known as the Wolds. The Lower Lias plain is the gathering ground of the River Smite, which has a sharply incised little valley where it crosses the escarpment at Colston Bassett, but a very shallow open valley above and below this point. The Nottingham and Grantham Canal takes advantage of the easy gradients of the Lias plain.

SUPERFICIAL DEPOSITS.—Prolonged erosion having removed any of the Mesozoic formations newer than the Lower Lias that may originally have existed in the district, there remains only to be considered the effect of the Superficial deposits of Glacial and Post-glacial times in shaping the land.

GLACIAL DRIFT.—Over the greater part of the area represented on the map there is a singular absence of Glacial deposits, in spite of the evidence that ice-sheets at one time covered most of the ground. The largest and most characteristic tract of drift is the boulder-clay already referred to as forming the plateau of the Wolds near the south-east corner of the map. This tract is merely the narrow northern end of a broad lobe or spur of boulder-clay which stretches southward into the great sheet of Chalky Boulder Clay that covers so much of the East Midlands. The surface of the lobe declines northward from well above the 400-ft. contour to about 300-ft. where it enters the present map. Where broadest it makes a remarkably even platform, but is trenched all round by small valleys of erosion, and finally reduced to a mere flattened ridge.

Patches of boulder-clay also cap the rounded summits of the Keuper tract south of the coalfield, and appear in some cases to be responsible for the origination or, at any rate, for the preservation of the hill-features.

Outside the main area of the boulder-clay there are patches of gravel, likewise of Glacial age, which occur similarly on ground higher than that of the immediate neighbourhood. Such gravelly patches cap some of the moundy hills on both sides of the Leen valley, of which Long Hill, a mile W. of Hucknall Torkard at over 400 feet above O.D., is the most conspicuous example. South of the Trent, Wilford Hill, rising to 284 feet, and a few other summits in the neighbouring Keuper country, are also gravel-capped.

The conditions during the closing stages of the Glacial epoch were evidently favourable to severe and rapid erosion, so that not only were the solid formations deeply trenched, but the recently deposited drifts were also much reduced in extent. It appears to have been at this time that the present valley of the Trent was excavated, and its oldest gravel terraces are probably of Late-glacial age.

RIVER GRAVELS AND ALLUVIUM.—The Trent meanders along a broad flat, varying from 1 to 3 miles in width, which is composed entirely of its old flood-gravels and later alluvial deposits of loam and silt. The flat is for the most part bordered on both sides by steep slopes of Keuper Marl, representing the original river-bluffs more or less worn down by weathering. The course of the river is predominantly toward the southern margin of the flat, influenced partly by the dip of the Keuper and partly by the detrital fans of the northern tributaries. In several spots on the south it swings quite up to the high border of the valley, excavating steep and picturesque bluffs of the red Keuper Marl; *e.g.*, Clifton Grove, Radcliffe, and Old Hill.

The oldest river deposits of the flat are the gravels, which are spread over its whole width but are now partly buried under more

recent accumulations of loam and silt. Where these gravels rise to the surface, they usually form ground elevated slightly above the flood-plain, and have therefore afforded the sites for a few villages in the valley, though most of the villages are situated along the edges of the flat.

TABLE OF FORMATIONS.

The following is a summary of the formations briefly described in the foregoing chapter, and represented on the map :—

Superficial Formations.

PLEISTOCENE	{	Recent...	...	...	Alluvium.
		Post-glacial	...	...	River Gravels.
		Late-glacial	...	...	Older River-gravels.
		Glacial...	...	...	Boulder-clay, with sand and gravel.

Solid Formations.

JURASSIC ...	{	Lower Lias	...	...	Shaly clays with thin limestones.
		Rhætic	...	...	Black and grey shales with nodular limestone.
TRIASSIC ...	{	Keuper Marl	...	...	Red and variegated marls with thin sandy bands ('skerry').
		Keuper Waterstones...	...	...	Thin flaggy sandstones and marl.
		Bunter Pebble Beds...	...	...	Soft sandstone or sand-rock with pebbles.
		Lower Mottled Sandstone (Bunter).	...	...	Red and variegated soft sandstone.
PERMIAN ...	{	Permian Marl	...	...	Red marls.
		Magnesian Limestone	...	...	Dolomitic limestone.

CARBONIFEROUS ...	{	Coal Measures	...	...	Shales and sandstones with coal-seams.
		Millstone Grit	...	...	Massive sandstone.

CHAPTER II.

CARBONIFEROUS.

INTRODUCTION.

Among the Carboniferous rocks of the Nottingham area the Coal Measures take the predominant place by reason of their width of outcrop in the Erewash Valley, and their underground extension beneath the Permian and Trias to the east and south-east, with the consequent accessibility of a large quantity of coal. The Coal Measures of the present area form only the southern part of a big synclinal fold which contains the coalfields of Yorkshire, Derbyshire and Nottinghamshire. Of this fold the northern margin comes to the surface north of Leeds, and the western boundary is continuously exposed from Bradford to the neighbourhood of Derby; but Permian and Triassic rocks conceal the southern and eastern limits, in which directions the Coal Measures have an underground extension of which the boundaries have not yet been proved. Coal-mining, however, is gradually revealing the structure and composition of the hidden portions, and in our area the explorations for coal assume particular interest in furthering our knowledge of the general structure of this, the largest, coal-basin in Great Britain.

In contradistinction to the dominant east-and-west folds in which the coal-basins of the South-eastern counties, Somersetshire and South Wales are involved, the coalfields of the north-eastern counties lie in a trough orientated north and south, parallel to the Pennine uplift. But they have also been affected by other folding at right angles, giving rise to the upturned edges of the Coal Measures north of Leeds and west of Nottingham. It will be shewn later that the major folding of the Carboniferous rocks was completed before the earliest Permian sediments were laid down, since these rest on the folded, eroded, and frequently highly inclined strata of the Carboniferous formation.

At their outcrop in the Erewash valley the Coal Measures attain a thickness of over 2,500 ft. To this must be added about 800 ft. of higher measures proved in the borings at Thurgarton and the shafts at Gedling colliery, thus bringing the total thickness of Coal Measures to well over 3,000 ft. The outcrop of the Millstone Grits, on which the Coal Measures rest, is restricted in our map to a narrow strip along the southern margin of the coalfield, but their underground course has been proved by borings at Little Hallam and at Ruddington. Between Ruddington and the valley of the Soar there is every reason to believe, from the evidence afforded by a boring near Hathern, that Carboniferous rocks older than the Millstone Grits form the floor of the Trias to the south-west of Ruddington. A considerable part of the Carboniferous sequence of the Midlands is therefore represented within the area, either at the surface in the "exposed coalfield" or hidden under newer formations in the "concealed coalfield."

CLASSIFICATION.

The following tabular statement gives the classification and nomenclature of the Carboniferous rocks in Derbyshire and Nottinghamshire according to the scheme generally adopted for the Midland coalfields, with the exception that the term Limestone Shales is used instead of Yoredale Rocks.

Division.	Subdivision.	Chief Characters.	Average thickness.
UPPER CARBONIFEROUS.	Upper Coal Measures.	Red sandstones and red marls. Grey sandstones and shales. Red marls and green grits.	Ft. 500
	Middle Coal Measures.	Grey sandstones and shales with numerous seams of coal.	2,000
	Lower Coal Measures.	Grey sandstones and shales with three seams of coal: gannister towards the base.	1,000
	Millstone Grit Series.	Massive grits with shales and thin coals.	1,300
LOWER CARBONIFEROUS.	Limestone Shales.	Shales with thin grits: earthy limestones in lower part.	400
	Carboniferous Limestone.	Thin-bedded and massive limestone, with layers of chert in the upper part.	not definitely known.

Each subdivision by possessing distinctive lithological characters or the preponderance of a particular type of rock constitutes a stratigraphical unit. Thus the Carboniferous Limestone, several hundred feet thick, forms practically an unbroken succession which in Derbyshire belongs for the most part, if not entirely, to the highest (*Dibunophyllum*) zone of Dr. Vaughan's recent zonal classification of the Lower Carboniferous rocks of Somersetshire. The Limestone Shales consist for the most part of shales and thin bands of earthy limestone. More than one half of the Millstone Grit Series consists of coarse, massive and wonderfully persistent grits. Fine-grained sandstones form the most conspicuous members of the Lower Coal Measures. The Middle Coal Measures are distinguished by the presence of numerous seams of coal; and the Upper Coal Measures by their thick red marls, green grits ('Espley' rocks) and red sandstones.

But while each subdivision has its special type of rock, the unity of the Carboniferous formation, insisted on by Jukes and favoured by Ramsay and Green, is shewn by the gradual passage of one lithological type into another; and, except in the case of the lowest limestones, by the presence of rock-bands common to all the subdivisions. Thus, seams of coal, though most abundant in the Coal Measures, occur in the Limestone Shales locally and in

the Millstone Grits generally; and red strata, though markedly developed towards the close of the period, are locally present in the Millstone Grit Series and Limestone Shales.

A distinction useful in coal mining in the Midland coalfields can be drawn between a "Grey Chief Coal-bearing Series," which includes the Lower and Middle Coal Measures, and a "Red and Grey Series" which includes the high measures found at Thurgarton.¹

The classification of the Carboniferous formation given above is essentially based on differences in lithological characters. We have next to enquire whether the life of the period, as represented by the fossils, affords a more definite basis of classification. As regards our area, the palæontological material at hand is insufficient to warrant even an attempt on these lines, but it may be useful to state briefly what has been accomplished by this method in other British coalfields.

In Scotland Dr. Traquair² demonstrates a complete change between the estuarine fish-faunas above and below the Roslin Sandstone, held to be the Scottish equivalent of the Millstone Grit. Dr. Kidston in his study of the plant remains also finds an equally well marked break between an Upper and a Lower Carboniferous flora within the Roslin Sandstone Series,³ and he has drawn this line a few feet below the lowest Millstone Grit in North Staffordshire; but in Derbyshire neither the fossil fishes nor the plants have been worked out among the strata below the Millstone Grits.

Among the Upper Carboniferous rocks the latest schemes of classification are those based on the vertical distribution of the plants. In the Yorkshire Coalfield, Dr. Kidston, on the evidence of the plants, has taken the horizon of the Silkstone Coal (Black Shale Coal or Clod Coal of Derbyshire) as the dividing line between the Lower Coal Measures below this coal and Middle Coal Measures between it and the base of the red measures seen around Conisboro'. More recently he has proposed the term 'Lanarkian Series' to include the Millstone Grits and Lower Coal Measures, and the term 'Westphalian Series' for the Middle Coal Measures.⁴ Above the 'Westphalian' Coal Measures of North Staffordshire and the equivalent Middle Coal Measures of other British coalfields Dr. Kidston recognises a 'Transition Series' to which he gives the name of the 'Staffordian Series.' This includes the Etruria Marl and Newcastle-under-Lyme groups met with in the boring at Thurgarton. Above these groups in North Staffordshire and also at Thurgarton some red sandstones and red marls, forming the Keele Group, are referred by Dr. Kidston to the Upper Coal Measures or to the 'Radstockian

¹ 'The Country between Newark and Nottingham.' *Mem. Geol. Surv.*, 1908, p. 10.

² 'Ganoid Fishes of the British Carboniferous Rocks,' part i., *Pal. Soc.* (1877); and, 'On the Distribution of Fossil Fish Remains in the Carboniferous Rocks of the Edinburgh District,' *Trans. Roy. Soc. Edin.*, vol. xl., part iii., 1903, p. 687.

³ 'Summary of Progress for 1903,' *Mem. Geol. Surv.*, 1904, p. 108.

⁴ 'On the Divisions and Correlation of the Upper Portion of the Coal Measures, with special reference to their Development in the Midland Counties of England.' *Quart. Journ. Geol. Soc.*, vol. lxi., 1905, p. 308.

Series' of his latest classificatory scheme. Continental palæobotanists, however, deny the existence in Britain of any Upper Coal Measures in the sense in which the term is applied in France, Belgium and Germany¹; nor has Dr. Kidston's latest terminology been generally accepted in this country. The old nomenclature is therefore retained in the following account of the local Carboniferous sequence.

MILLSTONE GRIT SERIES.

As previously mentioned, the Carboniferous rocks of the Erewash valley form part of a synclinal fold of which the southern and eastern margins are concealed under Trias. The oldest strata appearing at the surface in the fold along the south-western margin of the coalfield are the massive sandstones which belong to the First Grit or the highest member of the Millstone Grit Series. Where seen in the extensive quarries around Stanton-by-Dale the First Grit is a hard resistant rock over 70 feet thick, dipping north at 10 degrees, and though the base is not reached in the quarries the grit is known to be underlain by a considerable thickness of soft shales. These conditions are such as would lead to the development of bold scarp features facing south, and there is little doubt that this was the character of the landscape along the southern margin of the coalfield before the Triassic sediments levelled up the pre-existing inequalities. These bold features still remain buried south of Stanton-by-Dale, but to the north of Dalemoor Farm they are being slowly reinstated as the Trias is removed by denudation.

Though the Millstone Grits form a limited outcrop in the Erewash valley, a considerable thickness of these rocks has been proved at Little Hallam and Ruddington in borings which supply important information about the distribution of the Millstone Grits to the south-east of the Pennines. If the thickness of the Millstone Grits as proved in these two borings be compared with their development in the Derwent valley around Coxbench, it is seen from the following table that some increase in thickness takes place in a south-easterly direction.

Subdivisions of Millstone Grit.	Derwent Valley.	Little Hallam.	Ruddington.
	Feet.	Feet.	Feet.
Rough Rock, Top, or First Grit	100	118	137
Shale	50	15	} 160
Coxbench Grit	120	112	
Shale	90 } 250	102	
Belper Grit		147	110
Shale with thin gr.t at base ...		} 95	} 218
Shale	2		
Coal	2 $\frac{2}{3}$		
Upper Kinderscout Grit ...	80 — 300	400 +	109 +
Shale	0 — 75	—	—
Lower Kinderscout Grit ...	200	—	—

¹ A. de Lapparent, 'Traité de Géologie,' 1906, p. 926.

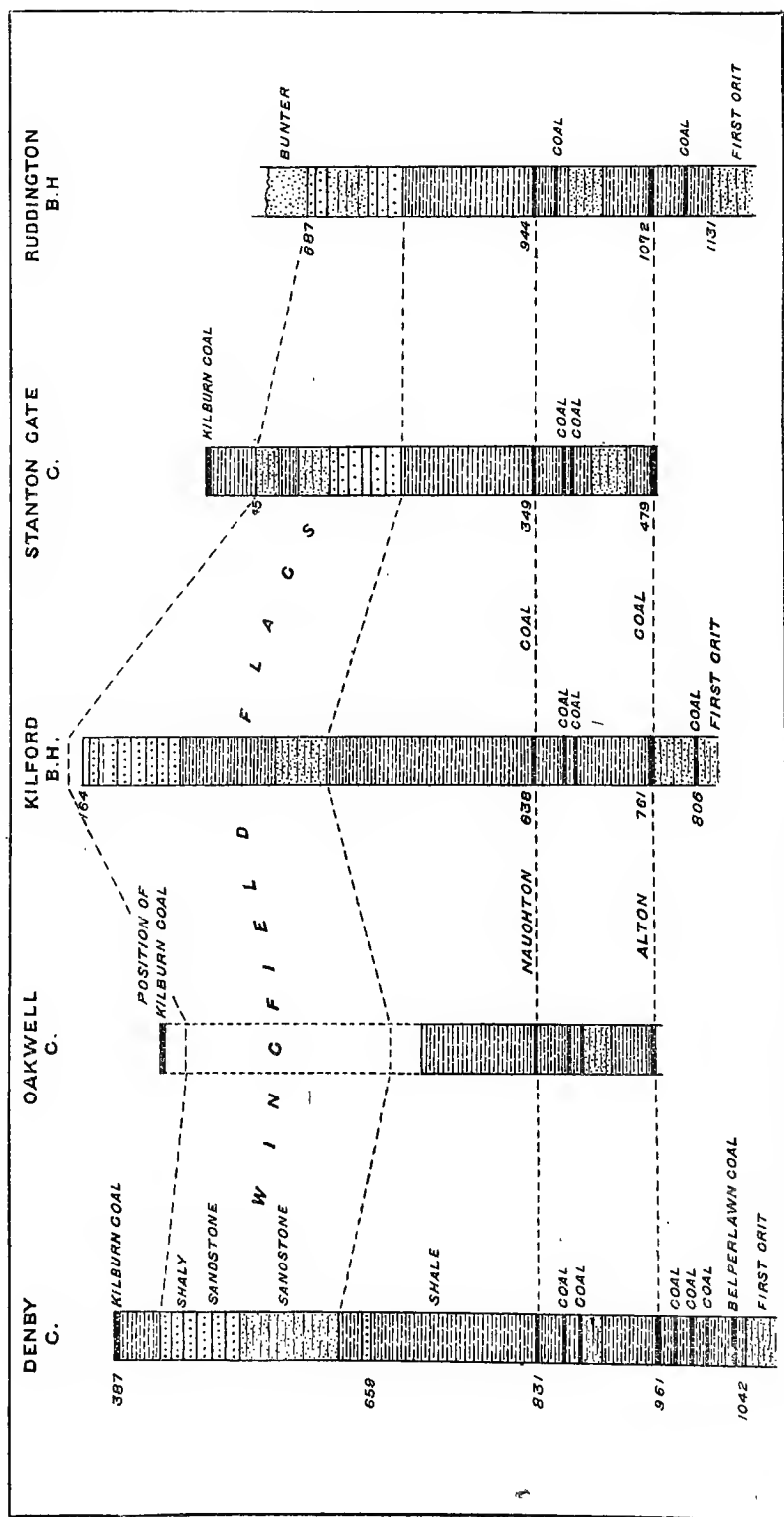


FIG. 2.—SECTIONS OF COLLIERIES (C) AND BORINGS (B.H.) IN THE LOWER COAL MEASURES.

The numerals are the depths from the surface in feet. Scale : one inch = 200 ft.

It will also be seen that the First Grit, Belper Grit and Upper Kinderscout Grit, which are the most persistent beds in the Derwent valley, maintain their individuality at Ruddington, so that it is reasonable to postulate their further extension to the south-east of Ruddington, along with the overlying and conformable Coal Measures. The study of the Millstone Grits, therefore, lends support to the view adopted by Prof. P. F. Kendall that the buried coalfield south of Nottingham has a considerable extension south-eastward.¹

LOWER COAL MEASURES.

The next belt of strata entering into the synclinal fold is composed of the Lower Coal Measures which immediately succeed the First Grit to the north of Stanton-by-Dale. This subdivision here locally assumes considerable importance since it contains the high-class coal-seam known as the Kilburn Coal. The subdivision includes all the measures lying between the First Millstone Grit and a seam of coal known alternatively as the Black Shale, Silkstone, or less commonly, Clod Coal. As the map shows, the main portion of the outcrop lies on the west side of the Erewash valley. Open sections are far from numerous, but portions of the subdivision are revealed in the old open-cast workings for ironstones (locally called 'rakes') between Stanton Gate and Dale, and in the abandoned quarries in a red sandstone between Lady Wood and the Hagg Colliery; mining information, however, supplements the data obtainable at the surface and permits a fairly accurate study of the measures.

The thickness of the Lower Coal Measures is approximately 1,000 feet, separable by the Kilburn Coal into two parts, possessing some distinctive characters. Below this seam the arenaceous members amount to less than half the total thickness, and are developed mainly in the Wingfield Flagstones, a group which sets in not far below the Kilburn Coal, and though variable is recognisable in all the sections between Denby and Ruddington. The relations of the flagstones to the underlying measures is shown by the sections in Fig. 2, from which it will be seen that the lower seams known as the Naughton (or Norton) and Alton coals maintain a constant relative position, but that, as is general in the Derbyshire Coalfield, the thickness of the measures between the Alton Coal and the First Grit is subject to variation.

Respecting the measures between the Kilburn Coal and the Silkstone Coal, the journals of numerous shaft-sections show that the arenaceous and argillaceous members are about equal in amount, and that two of the sandstones—the one above the Kilburn Coal and the one below the Silkstone Coal—maintain a nearly uniform thickness and character, but that the intermediate sandstones change from place to place.

In comparison with the main grits of the Millstone Grit Series the sandstones of the Lower Coal Measures are more felspathic, of finer grain, and of less definite individuality. The conditions under which they were deposited seem throughout to have remained fairly constant.

¹ 'Final Report of the Royal Commission on Coal Supplies,' pt. ix., 1905, p. 24.

A point of especial palæontological interest in the Lower Coal Measures is the occurrence of a marine band forming the roof of the Alton Coal. The best exposure of this band occurs in the Bullbridge Brick Pits at Ambergate, where the lower two feet at the base of about 20 feet of shale contains *Pterinopecten papyraceus* (J. Sow.); *Posidoniella minor* (Brown); *Lingula mytiloides* J. Sow.; *Gastrioceras carbonarium* (Von Buch); *G. listeri* (Mart.); *Glyphioceras bilingue* (Salt.).¹ Mr. R. D. Vernon informs us that small gasteropods are abundant and that the rare ichthyodorulite *Listracanthus*, hitherto only known to occur in the marine bed above the Top Hard Coal (p. 17), is also present². This marine bed has been recognised also in the borings at Ruddington and Kilford and was met with in a recent sinking at the Oakwell colliery, Ilkeston. Search for it might be made in the old open workings around Dale Moor.

Between the Alton Coal and the First Grit the following fossils were found in the Kilbourne sinking, Denby:—*Carbonicola acuta* (J. Sow.); *C. robusta* (J. de C. Sow.); *C. turgida* (Brown); *C. nucularis* Hind; *Naiadites modiolaris* (J. de C. Sow.); all of which likewise occur in abundance at several horizons in the measures above the Silkstone Coal (p. 17), as do the marine fossils mentioned above. Interest is also attached to the occurrence at the Kilbourne sinking of *Lepidodendron lycopodioides* Sternb., *Sphenophyllum cuneifolium* (Sternb.) below the Naughton Coal, since both of these plants have a wide range among the Upper Carboniferous rocks and are here unaccompanied by any distinctive Lower Coal Measure species.

MIDDLE COAL MEASURES.

The Middle Coal Measures which conformably succeed the Lower Coal Measures attain a thickness of over 2,000 ft., divisible at the horizon of the Top Hard Coal into a lower part, over 900 ft. thick, containing several workable and persistent coal seams, and an upper part, about 1,200 ft. thick, in which the seams, though numerous, are thin, impersistent and often unremunerative. This distinction between the two parts of the Middle Coal Measures extends over the entire Derbyshire and Nottinghamshire Coalfield. It is likewise prevalent in the Yorkshire Coalfield, where the coals above the Barnsley Seam, the equivalent of the Top Hard Coal, are noted for the irregularity of their occurrence. Some of the sandstones in the lower part of the Middle Coal Measures are fairly persistent, while few of those above the Top Hard Coal are continuous over extended areas. This difference affords evidence of a slight change in the conditions of sedimentation, and the conclusion is sustained by a slight change in the fauna at this horizon (p. 17). The Top Hard Coal can therefore be taken as a convenient divisional plane in a great thickness of strata. In our

¹ 'The Southern Part of the Derbyshire and Nottinghamshire Coalfield.' *Mem. Geol. Surv.* 1908, p. 100.

² 'Geology of the Lower Coal Measures of the Derbyshire and Nottinghamshire Portion of the Yorkshire Coalfield.' *Geol. Mag.*, dec. v., vol. vi, 1909, pp. 289-299.

area the line is especially suitable as a reference-datum, since the measures above the Top Hard Coal are for the most part only known in the concealed coalfield.

The coal seams of the lower group of the Middle Coal Measures, are of prime economic importance and likewise form convenient strata for reference. Their order of occurrence in descending sequence, with the thickness of the intervening strata in the Erewash valley, is given in the following table:—

	Thickness in ft.
TOP HARD COAL	— 6 to 8
Clays, marls and shales	50 —
DUNSIL COAL	— 3 to 4
Clays, shales, and thin sandstones	100 —
WATERLOO COAL	— 4
Shales, clays, and sandstones	400 —
DEEP SOFT, SOFT, or MAIN SOFT COAL	— 4 to 5
Clays, shales and ironstones	50 —
DEEP HARD, LOWER, BOTTOM, or MAIN COAL	— 5
Shales with thin sandstones	40 —
PIPER COAL	— 3 to 4
Shales, thin sandstones and ironstones	40 —
HOSPITAL, LOWER, or BOTTOM PIPER COAL	— 2 to 3
Shales and thin sandstones	125 —
FURNACE, TUPTON, LOWER MAIN, or LOW MAIN COAL	— 4
Shales, marls, and many ironstones... ..	170 —
BLACK SHALE, or SILKSTONE COAL	— 5 to 10

The measures below the Top Hard Coal occupy the centre of the syncline on the west side of the Erewash valley, but bend over on the east side where the dip quickly carries them under the Magnesian Limestone.

The seams of coal are seldom seen at the surface. The Waterloo Coal, however, crops out in a brick-pit at Loscoe Grange (Glue Lane); the Top Hard Coal and the measures above in the clay-pits at Stoney Lane; and the Tupton Coal in the brick-works at Oakwell Colliery. Measures and thin seams above the Deep Soft Coal are well shown in the clay-pits near Ilkeston Junction, and those associated with the Deep Hard Coal can be studied at Cossal. Large clay-pits, showing thin seams, have been opened near Newthorpe station, on a horizon above the Deep Soft Coal; and a few other sections mostly limited to these horizons are mentioned in the memoir in explanation of sheet 125 ('The Southern Part of the Derbyshire and Nottinghamshire Coalfield'). The thickness of strata thus open to examination is small, amounting only to about 200 ft. out of a total thickness of over 900 ft. Nor are the records of shafts and borings sufficiently complete to yield adequate geological information with respect to the character of the strata and their fossils, though they afford abundant data as to depths and thicknesses. A comparison of the shaft-sections from place to place shows a remarkable regularity in the arrangement of the sediments. Thus at Shipley the measures between the Silkstone Coal and Top Hard Coal are 958 ft. thick, and at Wollaton, six miles to the south-east, this amount has fallen to 867 ft. in accordance with the general though slight diminution in the thickness of the coal measures in a south-easterly direction. The vertical distances between intermediate seams also follow the

same rule, the Top Hard Coal being separated from the Deep Soft Coal by 541 ft. at Shipley, and by 519 ft. at Wollaton; and the Deep Soft Coal from the Deep Hard by 53 ft. at Shipley, and by 42 ft. at Wollaton. This regularity must, however, be regarded as local and not as applicable to the whole of the coalfield, though, as previously stated, the Middle Coal Measures below the Top Hard Coal are far more uniform in character than the portion of the measures above that coal.

In the Erewash valley open sections of the upper group are practically confined to the shales and sandstones immediately above the Top Hard Coal, which are admirably displayed in the many brick-pits between Kimberley and Brinsley. The sinking of the Gedling colliery also afforded opportunity for examining the whole thickness of the group, so that we possess somewhat fuller information respecting these strata than in the case of the lower group. The sequence as a whole is distinguished from the lower group by the absence of thick sandstones, the strata for the most part consisting of sandy shales, shales, and marls in alternating bands, irregular in their occurrence and possessing few distinctive lithological characters. Coal-seams are developed on several horizons but are not often mined, being impersistent and rarely exceeding 3 ft. in thickness, though some of them are being worked to a limited extent in the Leen valley. The available data are insufficient to determine with exactitude the relative thickness of the group at different places, or the directions in which variation takes place; but the beds increase collectively in thickness to the north or north-west in common with the rest of the Coal Measures. It is not known, however, whether the increase is gradual and uniform as in the case of the beds below the Top Hard Coal, or whether it takes place suddenly. Between Bestwood and Hucknall Torkard the increase is apparently gradual, but there may be a somewhat sudden diminution between Bestwood and Gedling.¹

As regards the fossils of the group it has recently been found that they possess many points of interest both to the stratigrapher and to the palæontologist, the researches of Dr. L. Moysey having not only added many life-forms new to the district, but also some new to science.

One of the most interesting of these additions is *Præanaspides præcursor* H. Woodw., a small crustacean having its nearest living representatives in freshwater pools on Mt. Wellington, Tasmania, and in small reedy pools near Melbourne, Australia.² The fossil occurs in the measures associated with the Top Hard Coal in a clay-pit near Shipley Common; and at the same locality Dr. Moysey, among other discoveries, has found more or less perfect specimens of *Belinurus* and *Eurypterus*, of which *Eurypterus moyseyi* H. Woodw., and *E. derbiensis* H. Woodw., are new species.³ Many specimens of the curious fossil *Fayolia*—considered by some palæontologists to

¹ 'The Country between Newark and Nottingham.' *Mem. Geol. Surv.*, 1908, p. 15.

² *Geol. Mag.*, dec. v., vol. v., 1908, pp. 385-396.

³ *ibid.*, dec. v., vol. iv, 1907, pp. 277-282; also see L. Moysey, "On *Palæoxyris* and other allied fossils from the Derbyshire and Nottinghamshire Coalfields, *Quart. Journ. Geol. Soc.*, vol. lxvi. (1910).

belong to the vegetable kingdom and by others to be the egg-case of a fish—have also been found by Dr. Moysey in the Middle Coal Measures, especially about the horizon of the Top Hard Coal.

The plants of the Middle Coal Measures are of much interest Dr. Moysey finding them to be abundantly represented both in number and species, and excellently preserved, in the ironstone nodules on several horizons between the Top Hard and Silkstone Coal.¹ From their mode of preservation it is anticipated that some of these specimens may throw light on obscure points in the anatomy, fructification and genetic relationship of the plants.

The local zonal distribution of the commoner fossils, of which the chief in point of number and general distribution are the lamellibranch genera *Anthracomya*, *Carbonicola*, and *Naiadites*, and the extent to which the different species of these genera are confined within definite limits, is not fully known; but it appears that *Carbonicola robusta* (J. de C. Sow.) does not occur above the Deep Soft Coal, while found at several horizons below this coal, and, as already mentioned (p. 14), in the Lower Coal Measures. As in other coalfields, *Carbonicola aquilina* (J. de C. Sow.), and *C. acuta* (J. Sow.), extend throughout the Middle Coal Measures, and occur likewise in the Lower Coal Measures. In the ironstones between the Tupton Coal and Black Shale Coal, *Carbonicola turgida* (Brown), in association with the previously mentioned species, is common in the Mapperley area. The range of the distinctive species of the genus *Anthracomya* has not been definitely fixed, but *A. phillipsi* (Williamson) occurs in the top beds of the Middle Coal Measures at Gedling, and Mr. R. D. Vernon informs us that *A. williamsoni* (Brown) invariably accompanies the roof shales of the Top Hard Coal.

These three genera are generally admitted to indicate fresh water and estuarine conditions, and, since they have a general distribution throughout the Lower and Middle Coal Measures, it would appear that during the greater part of the period the sea did not have access to the area. Marine incursions, however, are known to have occurred at three separate intervals during the deposition of the Middle Coal Measures. The earliest occasion is that indicated by a bed with marine fossils in the measures 300 feet above the Deep Hard Coal, and two later occasions by beds of similar type occurring among the strata above the Top Hard Coal. The earliest phase is not yet known to have extended into the Nottingham district, but is persistent over the Chesterfield area in Derbyshire. The two later marine incursions are now known to have extended over the whole of the North Midland coalfield, and evidences of these marine phases was found at Gedling colliery and at the Thurgarton and Oxtun borings.

In Yorkshire, Mr. H. Culpin has recently recorded² no less than four marine bands in the measures above the Barnsley Coal. Of the bands found in Nottinghamshire, especial interest is attached to that occurring at 355 ft. above the 'Top Hard Coal' of Gedling,

¹ *Geol. Mag.*, dec. v., vol. v., 1908, pp. 220-222.

² 'Marine and other fossils in the Yorkshire Coal Measures above the Barnsley Seam.' *Proc. Yorks. Geol. Soc.*, N.S., vol. xvi., pt. iii., 1908, p. 321.

which yields *Lingula*, *Orbiculoidea*, and *Productus*, since it undoubtedly represents the incursion which produced a marine bed occurring 625 feet above the same seam at Mansfield colliery, in which the fauna was particularly rich and varied, and strongly reminiscent of the fauna of the Limestone Shales.¹

UPPER COAL MEASURES.

The Lower and Middle Coal Measures on the east side of the Pennines generally agree in sequence and character with the same divisions on the west side in North Staffordshire and Lancashire, but the resemblance between the Carboniferous succession in the east and west was, until recent years, supposed to terminate at the top of the Middle Coal Measures, though Green² considered the red measures at Conisboro', in Yorkshire, to be on the same horizon as the red Upper Coal Measures of North Staffordshire. It was not until the cores of the Thurgarton boring were critically examined in 1899, that the red sandstones and marls of the so-called 'Permian' which surrounds the Staffordshire coalfields were found to have their equivalent on the east side of the Pennines.

The boring at Thurgarton yielded confirmatory evidence of the Carboniferous age of these red beds, not only by the presence of typical Coal Measure plants, such as *Pecopteris arborescens* (Schloth.), *P. miltoni* (Artis), *Neuropteris rarinervis* Bunbury, and *Sphenophyllum*, but also by the proof it afforded that these red beds are conformable to the Middle Coal Measures, and are unconformably overlain by the Magnesian Limestone. At Thurgarton the highest beds of the Middle Coal Measures are succeeded by 283 feet of red and mottled shales and marls, agreeing in character with the red and mottled marls which succeed the Middle Coal Measures of Staffordshire and are there known as the Etruria Marls. At Thurgarton, as in Staffordshire, these red beds contain the characteristic bands of green grits, known to the miner as 'Espley Rock,' which appear to have been in part derived from the waste of a glassy basic igneous rock, such as the 'Toadstone' of Derbyshire. Above these red measures the boring proved the presence of 91 feet of grey sandstones and shales, comparable to the Newcastle or Halesowen sandstones of Staffordshire, and the grey beds were overlain, in turn, by 188 feet of red sandstones and marls (containing *Pecopteris arborescens*, as mentioned above), on which rested the basal breccia of the Permian. The complete succession of the highest Coal Measures, as developed on the west of the Pennines is, therefore, present at Thurgarton, beneath the unconformable Magnesian Limestone.

STRUCTURE OF THE COALFIELD.

In the exposed coalfield the synclinal fold continues up to and beyond the northern limit of our map. It is traversed by a subsidiary anticline of which the axis, between Trowell station and Langley Mills, closely corresponds with the alluvium of the

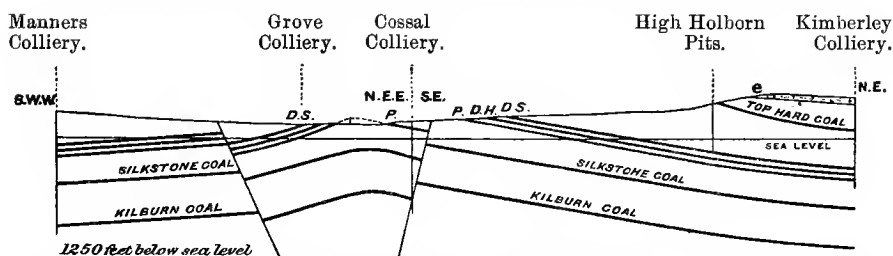
¹ 'Summary of Progress for 1905,' *Mem. Geol. Surv.*, p. 77.

² 'The Yorkshire Coalfield,' *Mem. Geol. Surv.*, 1878, p. 481.

Erewash valley (Fig. 3). On the east the Coal Measures maintain a nearly uniform north-west and south-east strike up to their disappearance under the Permian and Trias; but on the west the major fold includes the minor syncline of Shipley and Heanor (Fig. 4, p. 20), and the strike of the measures over the southern portion of the fold is nearly due east and west.

FIG. 3.—SECTION ACROSS THE EREWASH VALLEY ANTICLINE.

Horizontal Scale : $1\frac{1}{2}$ inch = 1 mile. Vertical Scale : = twice the horizontal.



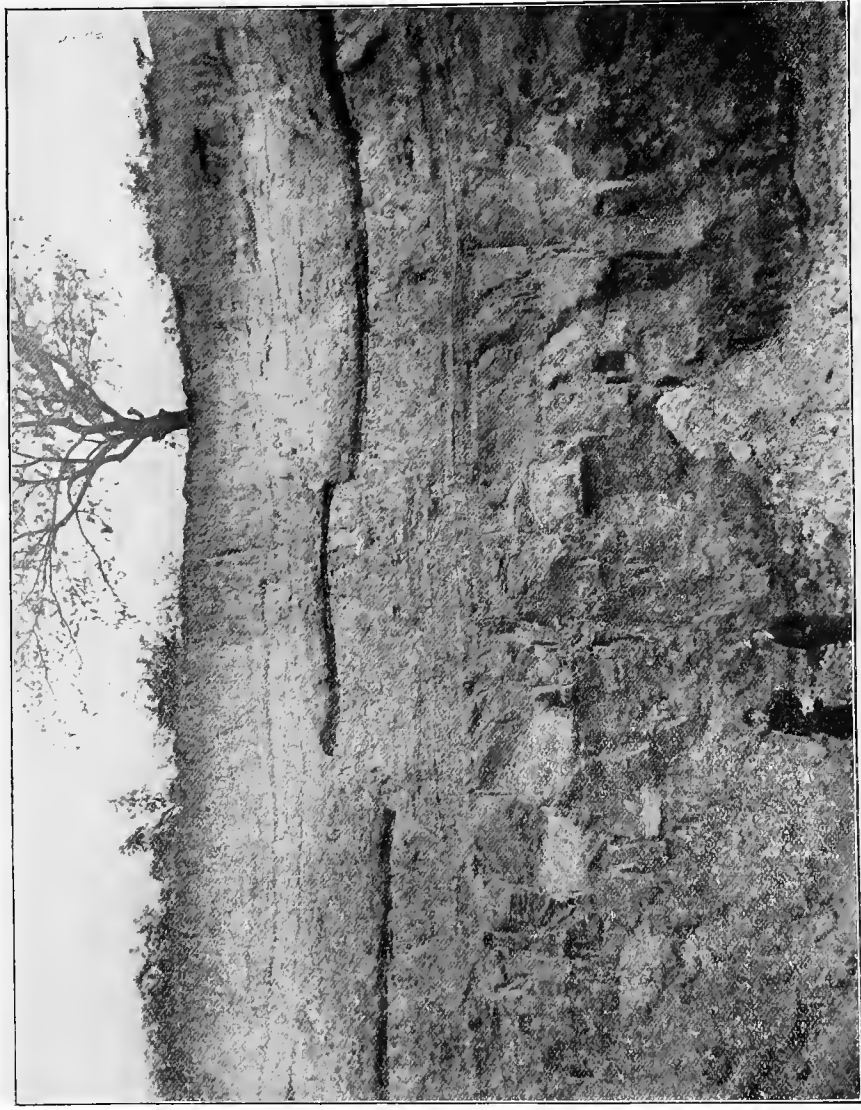
P. = Piper Coal, D.H. = Deep Hard Coal, D.S. = Deep Soft Coal. e = Magnesian Limestone.

In the concealed coalfield the north-west and south-east strike persists over the area north and north-east of Nottingham city, and the borings at Owthorpe, Ruddington and Edwalton indicate that this is the general strike of the Coal Measures for the south-eastern portion of our map.

Along the Erewash valley and to the west the dip of the coal measures, owing to folding, varies in amount and direction from place to place. To the east the general inclination is about 5 degrees over the exposed coalfield but it gradually diminishes to between 2 and 3 degrees on approaching the deeper and buried portion of the coalfield.

Numerous faults intersect the exposed coalfield, and the underground workings in the Leen valley and at Clifton have also proved the existence of several powerful fractures in these districts. The faults appertain to two systems, one having a general east-and-west direction, and the other trending north-north-west. Both are intimately related to the folding. Thus the Shipley syncline and Erewash valley anticline with axes trending north-west and south-east are margined by faults having the same direction; while the southern boundary of the coalfield between Dale and the Erewash valley, where the Carboniferous rocks trend east and west, is accompanied by an east-and-west fault. This suggests that some of the faulting of the Carboniferous rocks was brought about by the same movements as the folding, and this view is confirmed by some of the faults having a much greater displacement in the Coal Measures than they have in the Permian and Trias. Thus the E.-W. fault of 261 ft. vertical displacement in the coal measures at Cinderhill has only a trifling effect on the overlying Permian and Trias.

It is evident however that in other cases the faulting took place at a much later period, though the fractures followed the same direction as the older set. Among these later dislocations is the



COAL MEASURES WITH A THIN COAL, BROKEN BY SMALL FAULTS: IN A CLAY PIT AT GILT HILL,
NEAR KIMBERLEY.

From a photograph taken in 1893, by Professor F. J. Allen.

associated with the Top Hard Coal is shown in Plate II., from the photograph of a section until recently exposed in a clay-pit near Giltbrook. The faults in this case were only of a few feet and too small to be shown on the map. They are offshoots from a disturbance proved in the workings of the Digby colliery.

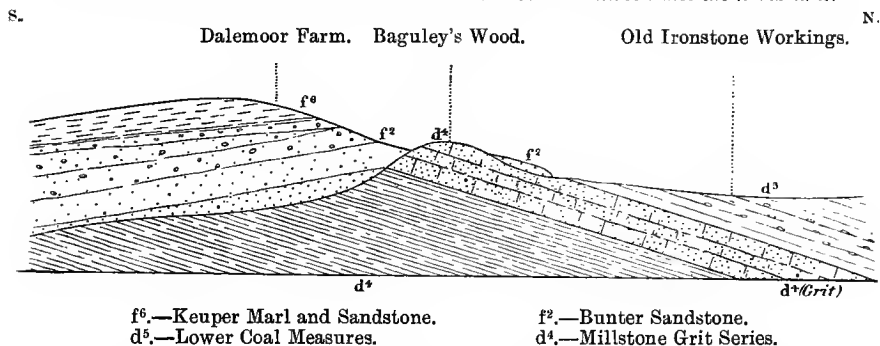
THE CARBONIFEROUS FLOOR.

Along the southern margin of the coalfield, as previously stated the Triassic rocks are inclined to the south while the Coal Measures dip to the north at a much higher angle than the Trias ; moreover, the Bunter Sandstone fills up irregular hollows excavated in the Carboniferous rocks before the Trias was laid down, as illustrated in Fig. 5.

FIG. 5.—SECTION NEAR DALE ABBEY, SHOWING EMERGENCE OF THE BURIED CARBONIFEROUS FLOOR.

(Reproduced from *Mem. Geol. Surv.*, 'The Southern Part of the Derbyshire and Nottinghamshire Coalfield.')

Horizontal Scale : 4 inches = 1 mile. Vertical Scale = three times the horizontal.



At their outcrop to the east of the Erewash valley the discordance between the Permian and Coal Measures is not at first sight so obvious, and in a few cases the two formations have the same inclination; but as a whole the Coal Measures are more steeply inclined, having a dip ranging from 5 to 10 degrees to the north-east, while the dip of the Permian rocks is never higher than 5 degrees and is directed due east. The effect of this discordance is that the Permian rests on measures several hundred feet above the Top Hard Coal near Beauvale Priory, and on measures below the Top Hard Coal at Catstone Hill, although the coal-measure surface under the Permian slopes evenly to the south-east and presents few or no irregularities. Again, on comparing the depths to the pre-Permian surface in the shafts and borings within the outcrop of the Permian and Trias between the Erewash and the Trent east of Nottingham City (*see* Folding Plate), the coal-measure surface is found to be inclined to the east-south-east at about 100 feet per mile. At Clifton colliery the base of the Trias (the Permian being absent) on the upthrow side of the large Clifton fault (p. 20) is 77 feet below sea level, while the base of the Permian is reached at 323 feet at Gedling, at 793 feet at

Thurgarton, and is 80 feet above sea-level at Bestwood colliery. There is, therefore, a general fall of the Carboniferous floor to southward and eastward from Bestwood over an area which has not been appreciably affected by post-Triassic faulting.

South of Clifton colliery the presence of several post-Triassic faults, with large throws but only proved for a limited distance in the colliery workings, prevents any accurate idea about the slope of the pre-Triassic surface, though the depths to the base of the Trias in the borings at Ruddington, Edwalton and Owthorpe (*see* Folding Plate of Sections) indicate that the average slope of the Carboniferous floor between these three points is slightly to the south of east at a gentle angle.

The question as to the prolongation and depth of the shelving surface of Coal Measures beneath the newer rocks is of great economic consequence, since upon these factors depends the future extension of the Nottinghamshire coalfield.

None of the borings through the newer rocks within our map have reached rocks older than the Millstone Grit, and, indeed, with one exception (Ruddington) they have not penetrated through the Lower Coal Measures. But a boring at Hathern, six miles south-west of Ruddington, proved the presence of rocks older than Carboniferous and probably of pre-Cambrian age beneath the Trias; and in the coalfields of Leicestershire and South Staffordshire similar ancient rocks are frequently reached, though in many cases the Carboniferous rocks intervene between the Trias and the ancient rocks. North of a line joining Nottingham and Market Drayton, however, formations older than the Carboniferous have not been pierced in any boring either within the area occupied by the North Staffordshire coalfield to the west of the Pennine chain or in the Nottingham-Yorkshire coalfield to the east of it, the Carboniferous rocks in both coalfields being several thousand feet thick. Hence the pre-Carboniferous floor within the Nottingham area lies beneath the zone of accessibility, except in the south-west.

SHAPE OF THE CONCEALED COALFIELD.

The present distribution of the Carboniferous rocks in the concealed area and likewise the slope of the exposed coalfield depend essentially upon two factors:—(1) post-formational folding, and (2) pre-Triassic denudation.

(1)—It is always recognised that the folding of the Coal Measures rocks is much more intense on the west side of the Pennines than it is on the east side where the plications are seldom more acute than those shown in the Shipley syncline and Erewash valley anticline (Figs. 3 & 4, pp. 19, 20). Moreover, the dip gradually diminishes on approaching the outcrop of the Magnesian Limestone; and the borings and shaft-sinkings between Nottingham and Doncaster prove further that the easterly dip continues to diminish beneath the newer formations, so that pits and borings sunk on the deep invariably encounter the Top Hard Coal at a less depth than they would do if the inclination remained the same as at the outcrop. In the concealed part of the coalfield, therefore, any folding which may exist is likely to be of the shallow open type, and we cannot anticipate any sharp plications to bring the Coal Measures near the surface.

The borings at Oxtou, Thurgarton and Owthorpe show beyond all question that the northern, eastern and southern limits of the concealed coalfield lie far beyond the margin of the map in these directions. We are therefore chiefly concerned with the position of the western boundary south of the Clifton fault.

At Ruddington under a cover of 687 ft. of Trias, 444 ft. of Lower Coal Measures are present and their base was reached at 1,131 ft. below the surface. The margin of the coalfield therefore lies somewhere between the boring at Hathern station (p. 22) and Ruddington, but it is impossible to locate the boundary more precisely.

We will next discuss the information obtainable from the exposed coalfield to the north of Stapleford. The Kilburn Coal, 480 ft. above the base of the Lower Coal Measures, crops out at Stanton Gate, and is 180 ft. deep at the Albany pit, the strike being a little north-of-east up to the Bramcote fault at Stapleford. This fault having a downthrow to the south will shift the outcrop to the west and the base of the Coal Measures may reasonably be placed near Sandiacre. But we have no data by which the strike of the measures can be determined between here and Ruddington.

On the west side of the Erewash valley, between Stanton-by-Dale and Dale Abbey, the Millstone Grit and Lower Coal Measures dip nearly due north; also at Castle Donnington, three miles south-west of Sawley, the Millstone Grits dip to the north. Presumably, therefore, the prevalent east-and-west strike of the Carboniferous rocks west of the Erewash is maintained over their concealed portion in the south-western area of the map, and there is no reason to expect the existence of Coal Measures in this quarter, unless there be narrow strips preserved in east-and-west folds or introduced by strike faults.¹

(2)—Within the concealed coalfield to the east of the Leen valley and south of the Trent, it is known that north-east of a line joining Gedling Colliery and Bestwood Colliery the Coal Measures are inclined at a higher angle than the slope of their old surface, so that higher measures are present at Thurgarton than at Gedling. The same relationship holds good of a line joining Clifton Colliery and Owthorpe. We may therefore anticipate that the higher Coal Measures will form the foundation of the later formations towards the eastern margin of the map.

IGNEOUS ROCK OF OWTHORPE.

Igneous rocks are intimately associated with the Carboniferous Limestone in Derbyshire, but among the Upper Carboniferous rocks of Nottinghamshire the only hitherto recorded occurrence is the dolerite found in the Middle Coal Measures in the boring at Owthorpe. This rock, judged by its petrological character, is intrusive, but it is uncertain whether the intrusion was pre-Triassic or post-Triassic; it may even be Tertiary.

¹ Shipman introduces on his map rectangular and faulted strips of Coal Measures, south of Stony Clouds, west of Belvoir House, Sandiacre, in an area represented as Waterstones on our map. We could obtain no evidence in support of his view. See 'The Geology of Stapleford and Sandiacre,' *Trans. Notts. Nat. Soc.*, 1891, pp. 10-19.

CHAPTER III.

PERMIAN.

INTRODUCTION.

We have laid stress in the preceding chapters on the great break or unconformity that occurs in the North Midlands between the Carboniferous rocks and the strata which cover them. The time represented by this unconformity is long, since in the interval the Carboniferous sediments were not only consolidated and uplifted, bent into folds and faulted, but were also deeply pared down by erosion, so that the Permian strata of the north of England rest indiscriminately upon all the members of the older system in turn. Nevertheless there is no group of the Carboniferous system absolutely lacking in the Nottinghamshire sequence, since borings have proved that even the Upper Coal Measures are present beneath the Permian, east of Nottingham (p. 18), though they nowhere reach the surface. Therefore it is clear that the main portion of the erosive work represented by the unconformity was not accomplished until after the accumulation of the Upper Coal Measures, that is to say, until the Permian period had commenced. Hence the first part of the period in this region was a time of erosion and not of deposition, and the Permian strata of Nottinghamshire represent only the later or 'Zechstein' division of the whole Permian system developed in Germany and other countries, while the earlier or 'Rothliegende' division has no representative.

The Midland deposits are of peculiar character, and have probably been accumulated in a shallow gulf or inland sea which gradually invaded the eroded land-surface of Carboniferous rocks. The outcrop in our district is the termination of the great belt of Permian strata which stretches along the north-east of England southward from the Tyne. The persistent attenuation and changing character of the deposits as they approach this termination strongly suggest that we are here approaching the original southern shore of the ancient sea. Therefore the overlap of the Triassic deposits upon the Carboniferous rocks along the southern margin of the Erewash Valley does not necessarily establish the unconformable relationship of the Trias to the Permian which the map seems to imply, for in this quarter the Trias has probably overspread an area beyond the reach of the Permian sediments. In fact, wherever the contact of the Permian and Trias is visible in the Nottingham district, the two formations are apparently conformable, and in a few places there are intercalations of marl and sand near their junction which suggest an upward passage of the Permian Marl into the Bunter Sandstone, as described by Mr. R. L. Sherlock in a previous memoir of the Survey,¹ and also by E. Wilson.² Farther north, however, beyond Mansfield, the emergence of higher

¹ 'The Southern Part of the Derbyshire and Nottinghamshire Coalfield,' (Sheet 125), 1908, pp. 115-116 and Fig. 8.

² "On the Permians of the North-east of England," &c., *Quart. Journ. Geol. Soc.*, vol. xxxii, 1876, p. 533.

subdivisions of the Permian from beneath the Trias was interpreted by W. T. Aveline, who first surveyed this tract, as implying the unconformity of the Trias,¹ and this relationship still to some extent remains an open question.

At its outcrop in the northern part of the map the Permian has a total thickness of about 50 ft., which is gradually reduced southward up to the final disappearance of the formation in the north-western outskirts of Nottingham. Its absence beneath the Trias in the country south of Nottingham has been proved by the shafts of the Clifton colliery and the deep borings at Edwalton, Ruddington and Owthorpe (*see* sections on Folding-Plate). On the other hand, to the eastward of its outcrop it is known to continue with increasing thickness beneath the Trias.

The Permian is divided on the map into two members; (1) Magnesian Limestone; and (2) Permian Marl. There is, besides, at the base of the formation in some places, an interesting Basement Breccia, which in the present area is too thin and 'patchy' to be separately indicated, but attains mappable development at a short distance to the northward. Also, the Magnesian Limestone itself may be locally subdivided, its lower portion sometimes showing distinctive lithological characters and fossils which have suggested its correlation with the Marl Slates of Durham. The formation is, however, essentially so variable, that the Magnesian Limestone division has, in this district, been regarded as a stratigraphical unit. The general characters of these divisions and subdivisions will be described in ascending order; for fuller details of the sections and exposures the reader should consult the separate memoirs on sheets 125 and 126.

MAGNESIAN LIMESTONE SERIES.

PERMIAN BRECCIA.

The best, and indeed the only clear exposures of the basal breccia within the limits of the map are in the cuttings of the Midland and Great Northern railways at Watnall and Kimberley. These sections were studied and described when fresh by E. Wilson²; and though now partly obscured they still show the breccia resting unconformably upon shaly Coal Measures, the best exposures at present being in the excavation for the sidings at the Great Northern station at Kimberley. It was formerly visible in the cuttings to the eastward for three-quarters of a mile, unconformably resting, with gentle undulations and a low dip averaging 3 or 4 degrees, on a planed-off surface of the Coal Measures in which the dip was over 15 degrees. Where present the breccia varies in thickness from an inch or two to a few feet, being, for example, 4 ft. 8 ins. thick in the cutting of the Midland Railway at Watnall tunnel and about 6 ins. in the same cutting near the Station. It consists of angular, sub-angular and rounded fragments derived from the Carboniferous rocks, including Millstone Grit and Carboniferous Limestone, together with bits of

¹ 'Parts of Nottinghamshire and Derbyshire' (Quarter Sheet, Old Series, 82 S.E.), 2nd ed., 1879, p. 19.

² *Op. supra cit.*, *Quart. Journ. Geol. Soc.*, vol. xxxii., p. 533.

slate, chert and other rocks from older formations, firmly cemented in a sandy calcareous matrix. The fragments are mostly small, averaging an inch or two in greatest diameter, but occasionally ranging up to 3 or 4 inches.

This breccia appears to have been formed on the slowly subsiding shores of the Permian gulf or sea, and the imperfect rounding of its material implies the absence of strong wave-action.

MARL SLATES.

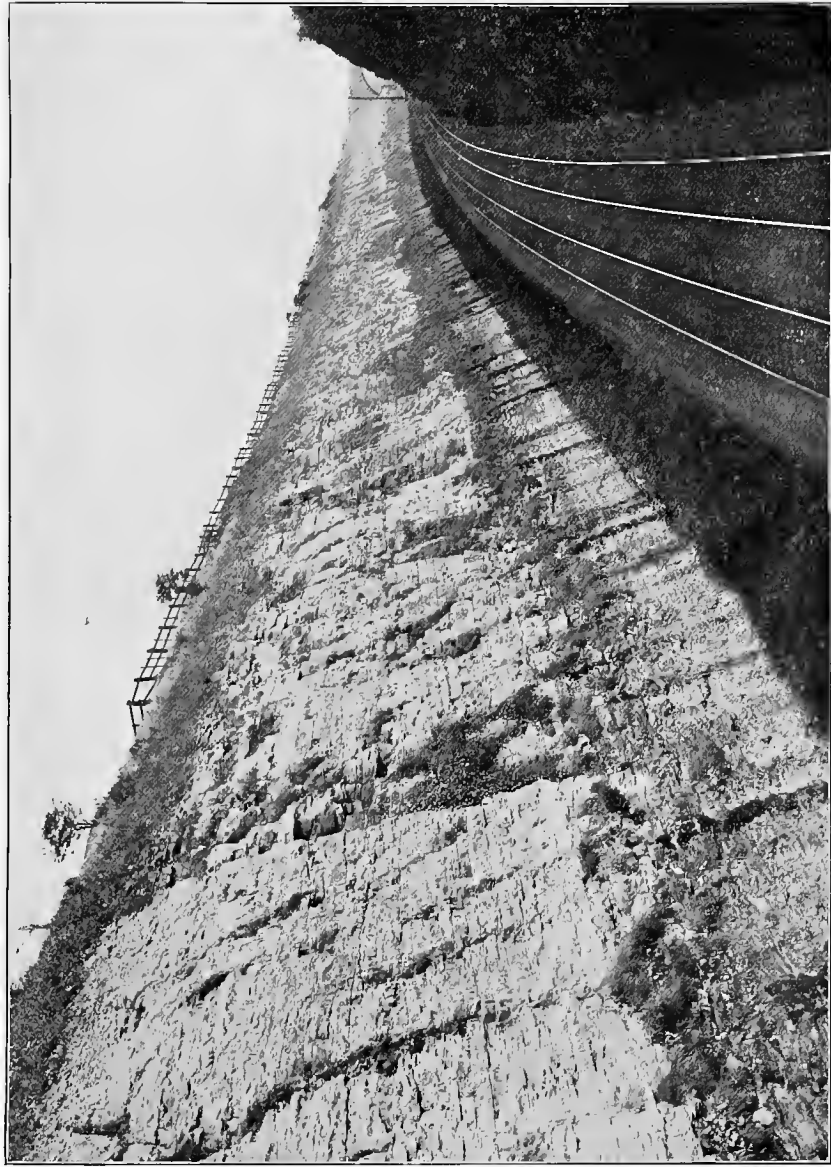
In the Kimberley district the lower part of the Magnesian Limestone Series is an impure sandy dolomite of greyish colour, occurring in thinly-bedded flags with shaly intercalations of grey marl or clay. In the deep cutting of the Great Northern Railway near Nuthall (*see* Pl. III) these beds are 17 ft. thick, but they dwindle to 3 or 4 ft. toward the southern termination of the Permian near Wollaton. The more sandy bands toward the base generally contain carbonized fragments of plants, while casts of shells (*Schizodus*, *Mytilus*? etc.), are locally abundant in some of the higher calcareous bands. In the shafts of the Gedling colliery these beds yielded *Pleurophorus costatus* (Brown), *Bakevelliä bicarinata* King, *Bakcv. antiqua* (Muenst.), and *Schizodus* sp.; and at the Thurgarton boring, they contained *Productus horridus* J. Sow.. In their eastward underground extension the deposits of Marl Slates type appear to become predominant in the Magnesian Limestone Series. In the outcrop north of Kimberley, the subdivision though rarely exposed is probably continuous, but is difficult to distinguish by surface indications since it weathers to a stiff soil very like that of the underlying Coal Measures.

The deposits of this type indicate the continued proximity of land; and they may be classed locally along with the Breccia as "Permian Basement Beds."

MAGNESIAN LIMESTONE.

Though comparatively thin, the Magnesian Limestone proper shows a relatively wide outcrop in the map owing to its long easterly dip-slope on the western side of the Leen valley. In this tract it is usually a brownish-yellow rock having a porous granular aspect, at first sight resembling a sandstone, but composed almost entirely of rhombohedral crystals of dolomite which are readily seen by the aid of a pocket-lens. It is more thickly-bedded than the underlying Marl Slates, but has still for the most part a somewhat flaggy structure, with occasional films of green marl on the bedding planes; and there is an absence of the massive character assumed by some parts of the formation where it attains greater thickness in the country north of the present map.

There has been much discussion whether the dolomite or complex double carbonate of lime and magnesia was originally deposited in this form owing to some peculiarity in the chemical composition of the Permian sea, or whether the rock was at first a normal limestone and subsequently altered by magnesian infiltration. It is generally recognized, however, that the state of the sea was



MAGNESIAN LIMESTONE SERIES IN THE G.N. RAILWAY CUTTING BETWEEN KIMBERLEY AND NUTHALL.
The division between the Magnesian Limestone and the Marl Slates is shown by the belt of vegetation due to seepage of water. (N.B.—The dark base of the section is due to shadow.)

abnormal, as indicated by the peculiar fauna and other circumstances. Probably the waters occupied an isolated inland basin, like the present Caspian Sea, and the conditions were such that even if the deposits were at first pure limestone, they became dolomitized soon after their accumulation.

Whatever its origin may have been, the presence of thick and wide-spread masses of dolomitic limestone is a salient characteristic of the Permian system not only in the east of England, but also throughout central and eastern Europe.

In the northern part of the map the Magnesian Limestone has a thickness of 30–40 ft., which diminishes gradually southward up to its termination. Eastward, at the Gedling shafts and the Thurgarton boring, the Permian strata were respectively 47 ft. and 93 ft. thick, but it became difficult in these sections to distinguish the limits of the subdivisions.

At its outcrop the average dip of the formation is toward E. by S., at about 1 to 2 degrees only. In the open exposures its only fossils are a few obscure casts of shells (*Schizodus*, etc.), which may be found in the quarries at Bulwell and Cinderhill. The rock is well exposed in several railway cuttings, particularly those of the Great Northern Railway (see Pl. III); of the Midland Railway between Bulwell and Kimberley; and of the three railways running north near Hucknall Torkard. There are also quarry-sections in many parts of the outcrop, of which the largest are those in the neighbourhood of Bulwell and Cinderhill, where the rock is quarried for building-stone and lime. The most southerly exposure is in an excavation 700 yds. south of Aspley Hall, near Radford, where about 8 ft. of sandy dolomite is revealed. The rock was also seen near its southern termination by Wilson in excavations at Bobbers Mill,¹ and by Shipman in other openings around and to the north of this place.²

PERMIAN MARL.

The upper division of the Permian system in the district north-west of Nottingham consists of shaly bright-red clay or 'marl' interspersed with green layers and thin hard bands of dolomitic sandstone. Between Bulwell and Hucknall Torkard this group has a thickness of 10–30 ft., but disappears south of Bulwell, either by thinning-out or by the overlap of the lowest beds of the Trias. It has generally been considered that the marls represent the Middle Marls of the Permian sequence in the country farther north, where they are overlain by an upper division of the Magnesian Limestone;³ and this correlation, if sustained, appears to imply an unconformity between the Permian and the Trias. The unconformity is not, however, directly evident in the present district, where, on the contrary, there is, as previously mentioned, not only a general parallelism between the two formations but some indications

¹ *Op. supra cit.*, *Quart. Journ. Geol. Soc.*, vol. xxxii., p. 534.

² See 'The Country between Newark and Nottingham' (Sheet 126) *Mem. Geol. Surv.*, 1908, p. 28.

³ W. T. Aveline, in *Mem. Geol. Surv.* 'The Country around Nottingham' (Old Series, Quarter-Sheet 71 NE.), 2nd ed., 1880, p. 18; and 'Parts of Nottinghamshire and Derbyshire' (O.S. ¼ Sheet 82 SE.), 2nd ed., 1879, p. 18.

of passage and interdigitation at the junction of the Permian Marl with the Lower Mottled Sandstone of the Trias. This apparent passage is best seen in a section on the Great Central Railway north of the Annesley tunnel, about 3 miles beyond the northern limit of the present map;¹ and it was also noticed by Wilson in the railway cuttings at Hempshill near Kimberley.²

The Marl supplies good material for the manufacture of bricks and tiles, and the best exposures are in brickyard excavations. The following section from the Cinderhill Brickworks, near Bulwell, shows the whole thickness of the division :—

			Ft.	In.
BUNTER	...	Red and mottled sand or soft sandstone	12	0
		{ Dolomitic flagstone	2	0
		{ Red marl	1	10
PERMIAN MARL		{ Dolomitic flagstone	2	0
26 ft. 10 in.		{ Red marl	3	6
		{ Red marl with thin bands of flagstone	12	6
		{ Red marl with sandy partings	5	0
		Magnesian Limestone	—	

At the shafts of the Bestwood colliery the Marl was 19 ft. thick, but it was absent at the Newcastle colliery, Basford. It was about 8 ft. thick (including sandy intercalations) in a boring at Woodborough, near the northern limits of our map; and 35 ft. thick in the Thurgarton boring.

No determinable fossils have been found in the Marl, but the surfaces of the dolomitic flagstones intercalated with it are often covered with curious markings which may be the trails of organisms. The general character of the deposit suggests that it has been the sediment from the still waters of a shallow enclosed sea or salt-lake.

¹ 'Southern part of the Derbyshire and Nottinghamshire Coalfield' (Sh. 125). *Mem. Geol. Surv.*, 1903, Fig. 8, p. 116.

² *Op. supra cit.*, *Quart. Journ. Geol. Soc.*, vol. xxxii., p. 533.

CHAPTER IV.

TRIAS.

INTRODUCTION.

As noted in our Introductory chapter, rocks of Triassic age largely predominate in the area of the map, and present features which enable us to classify them into divisions and subdivisions. In Nottinghamshire the major divisions are two, viz., Bunter and Keuper—and not three as in Germany where the system-name originated.

To account for their peculiar characters we must suppose that the strata where deposited in some inland basin of a wide continent, where the surroundings were of the arid desert type. We have seen that the beginning of such conditions is indicated by the Permian rocks; but the Permian fauna, while scanty and abnormal, was still distinctly of the marine facies. In the Trias of the district, however, no indication of marine influence is found until we reach the topmost subdivision of the system—the Rhætic—which bears evidence to the invasion of the Triassic basin by an encroaching sea. The great rarity of fossils in all the sediments between the Permian and the Rhætic is remarkable, and though partly explained by the unsuitability of the rocks for preserving organic remains, this peculiarity of composition itself implies a relative paucity of organic life in the district during the period.

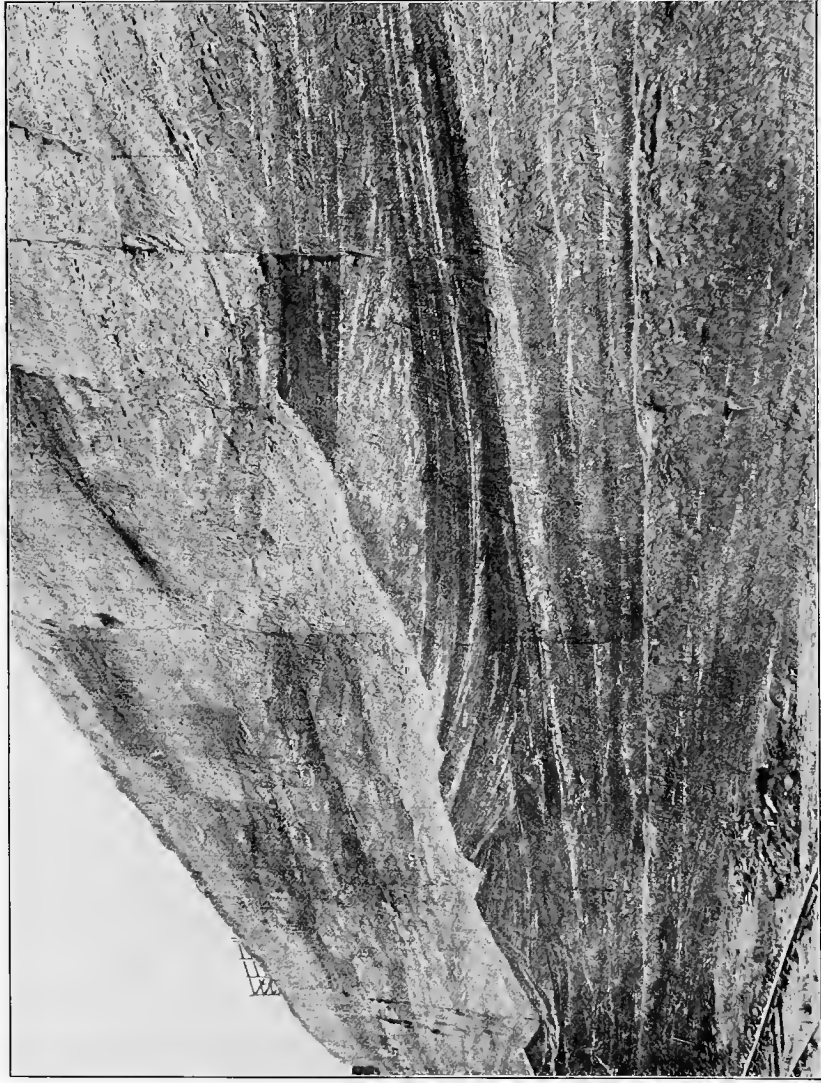
The sands and pebble beds of the Bunter probably represent the detritus swept into the lowlands, sometimes from distant sources, by the floods of seasonal rivers, while the marly deposits of the Keuper appear to have been accumulated in the shallow but more or less permanent waters of a large salt-lake in which the land-drainage was entrapped and evaporated.

In the following description, the subdivisions of the Trias are dealt with in upward sequence.

BUNTER.

The Bunter deposits of the country north of Nottingham are separable by differences of texture and structure into two subdivisions, the Lower Red and Mottled Sandstone (or, shortly, the Lower Mottled Sandstone) below, and the Pebble Beds above. West of Nottingham, however, where the Bunter overlaps the Carboniferous rocks, the whole of the beds in many places assume the pebbly character of the upper group, and it is only here and there that the lower subdivision is recognizable, so that the Lower Mottled Sandstone is not shown separately on the map in the Bunter outcrop west of Wollaton Park. If sediments of the Lower Mottled Sandstone type were ever continuous in this quarter, which is very doubtful, the major portion of them were removed by erosion before the Pebble Beds were deposited.

As described in the preceding chapter, where the Bunter rests upon the Permian Marl the two formations show a general parallelism of bedding and strike, and if there be any unconformity



LOWER MOTTLED SANDSTONE IN THE RAILWAY QUARRY AT HEMPSHILL.

A good example of current-bedding.

near Bulwell, shown in Pl. IV. The predominant south-easterly dip of this structure in the Nottingham district implies that the water-currents bringing the sands flowed mainly from the north-west.

The loamy and slightly adherent properties of the deposit render it of value as a moulding-sand; and for this purpose it has been largely quarried near Lenton, Radford, Basford and other places along its outcrop, though the largest excavations are near Mansfield, some miles north of our area. Good sections are revealed in these pits and in some of the numerous railway-cuttings around Bulwell; but the Lower Mottled Sandstone rarely weathers out into natural crags as the Pebble Beds do, its softer character and more ready disintegration giving rise to smooth concave slopes which merge gradually into the flat of the Permian Marl.

In a few places, the base of the Lower Mottled Sandstone is formed by a band of breccia or conglomerate, locally swelling to a thickness of several feet, more frequently developed where the Bunter rests directly upon Coal Measures. Where the Bunter rests upon the Permian Marl, instead of a basal breccia it occasionally shows intercalations of sand and marl which have the appearance of passage-beds, as previously described (p. 28).

The basal breccia was exposed in excavations for the gasholder at Old Radford in 1879-80, where the following section was observed by J. Shipman¹ :—

Soft sandrock of the usual type	...	...	...	ft.
Hard compact purplish sandrock	...	...	...	10
Brecciated conglomerate, thickest on the east side of the excavation and resting on a planed off and even surface of Coal Measures	...	...	...	4
	...	...	...	2 to 8

Shipman describes the conglomerate of this section as being “mainly composed of fragments of the underlying greenish and mottled Coal Measure shales, along with rolled quartzite pebbles, and an abundance of subangular fragments of felspathic, granitic, and other igneous rocks, most of them being too decomposed for examination under the microscope.” A similar breccia, near the base of the Lower Mottled Sandstone in the Great Northern Railway cutting at Hemphill, has been described by E. Wilson² as containing “semi-angular green, blue, and purple slates, more or less rounded grits, quartzites, quartz-breccia, and numerous white and discoloured slabs and nodular balls of Fossiliferous Carboniferous Limestone chert.” Another lenticular band of breccia of this kind, reaching a thickness of 6 ft., occurs in the Lower Mottled Sandstone at Kimberley Knowle; and a further example is exposed near Cinderhill colliery.

As regards the upper boundary of the Lower Mottled Sandstone, the finer textured sands occasionally give place upward at a distinct horizon to the coarser and cleaner sands of the Pebble Beds; but more often the subdivisions are not readily differentiated as their junction is approached. Evidently some slight change of conditions occurred, by which more powerful floods swept over the

¹ ‘Geology of the Parish of Lenton,’ in Godfrey’s ‘History of the Parish and Priory of Lenton,’ p. 22, reprint.

² *Quart. Journ. Geol. Soc.*, vol. xxxii., 1876, p. 533.

district at intervals, bearing the heavier sediments that form the Pebble Beds.

The thickness of the Lower Mottled Sandstone in the northern part of the map is about 80 ft., diminishing in the immediate neighbourhood of Nottingham to about 30 ft.

PEBBLE BEDS.

The Bunter Pebble Beds of the Nottingham district do not assume the character of true shingle-banks which they present in parts of Staffordshire and elsewhere, but are mainly composed of rather coarse sand with a somewhat sparse admixture of pebbles, which sometimes occur isolated and sometimes in broken strings and clusters, but rarely in segregated masses. This curiously scattered distribution of pebbles of all sizes in the sandy matrix is a striking characteristic of the Bunter of Nottinghamshire. The sand is sufficiently compact and indurated to form a sandrock, but is usually not consolidated beyond the point at which it can be crumbled readily between the fingers. Yet it is firm enough to stand with a vertical face when excavated and to maintain its surface for a long time with slight impairment, as it perishes very slowly under ordinary weathering. This quality combined with its massive structure, strong clean-cut vertical joints, and few bedding-planes, causes the rock to form bold crags in many places along its steep escarpment where carved out by sub-aerial agents, stream-erosion, or human workmanship. The Castle Crags at Nottingham (Pl. V.), rising over 130 ft. above the river-flat beneath them, afford a magnificent example of the forms assumed by the Pebble Beds under such circumstances, while similar crags of less imposing dimensions form a more or less continuous border to the broad valley of the Trent throughout the city of Nottingham, gapped only by the short hollows eroded by temporary rivulets in their descent to the main valley. It is in one of these dry tributary hollows, flanked by the crags of the Castle, that the city of Nottingham has had its beginning and still has its centre, on the line of the old main road which here found the easiest pass up the bluffs.

It is curious how persistently, in its long course, the river Trent adheres to the Keuper outcrop. In Nottinghamshire, only this once, along the front of Nottingham city, for about $2\frac{1}{2}$ miles, does it impinge upon the Bunter, or indeed upon any other formation than the Keuper; and even here, the aberrance is, as it were, accidental, the Bunter having been brought suddenly athwart the river by the upthrow of the Clifton Fault (p. 20). Moreover, immediately that it has felt the change, the river has swerved into a more easterly course to regain its favourite formation; the left side of its valley alone has broken into the Bunter, while the right side, at West Bridgford, opposite to Nottingham, is still in the Keuper Marl; and to this side the river now hangs, so that it is only for a short space in the vicinity of the Trent Bridge and in the loop north of Wilford,¹ that the present river-channel has a floor of Bunter.

¹ See 'The Country between Newark and Nottingham,' *Mem. Geol. Surv.*, 1908, pp. 22 and 35.



THE CRAGS OF NOTTINGHAM CASTLE. BUNTER PEBBLE BEDS.

While the Nottingham bluffs have primarily owed their origin to the erosive agency of the Trent, and of its tributary, the Leen (which appears formerly to have swerved sharply eastward on reaching the main valley), they have evidently been accentuated and preserved by human intervention. The Castle Crag, for example, could not have retained the sharpness of their base when no longer washed by the river, except by the removal of talus which would otherwise have accumulated, to the detriment of their defensive service. The celebrated "Mortimer" stairway cut into the head of the Castle rock and the chambers on its outer face are examples of the artificial work that has been carried out in this easily excavated material. In many other parts of the bluffs, the rock has been hollowed out for warehouses and other purposes, and the débris removed; indeed, it is still the custom to excavate rock-cells under the houses in some parts of the city.

Natural and artificial exposures of the Pebble Beds are so numerous in the crags, road-cuttings, railway-cuttings, etc., in almost every part of Nottingham city that it is needless to particularize them. Similar exposures are also visible at frequent intervals all along the outcrop up to the northern edge of the map.

West of Nottingham, along the southern margin of the coalfield the rock again forms natural crags near Sandiacre, and south of Dale Abbey; while in the Bramcote district, on the eastern side of the Erewash valley, there is the much visited stack or pillar known as the Hemlock or Himlack Stone which rises quaintly to a height of 31 ft. in the grassy depression between the wooded hills of Stapleford and Bramcote. In this quarter the higher portion of the Bunter, which forms the capping of the hills just mentioned and also of the Hemlock Stone, is a hard conglomerate with barium sulphate as a cement. It was urged by J. Shipman that the conglomeratic rock should be separated from the Bunter division and regarded as the basement bed of the Keuper,¹ but this opinion has since been controverted (p. 34). North of the main escarpment, the small outliers of the Bunter shown on the map around Strelley, Kimberley and Watnall form isolated hills that rise conspicuously above the Permian outcrop, Catstone Hill near Strelley being capped with hard conglomerate similar to that above-mentioned.

The irregularity of the surface of Carboniferous rocks on which the Bunter rests everywhere west of Lenton is clearly displayed in the neighbourhood of Dale. Here, steep ridges of the ancient surface, caused by the outcrop of the harder sandstones of the Carboniferous sequence, are enwrapped and concealed by the pebbly Triassic sands, but emerge in bold features where the Bunter has been recently stripped away from them. These conditions are illustrated in the cross-section, Fig. 5 given in Chap. II., p. 21. In a sandpit at Hagg, adjacent to the cross-roads $\frac{1}{2}$ mile NW. of Dale, the Bunter contains subangular and imperfectly rounded blocks of Carboniferous sandstone ranging up to 3 ft. in

¹ Shipman summarized his views in the handbook for the British Association Meeting at Nottingham, 1893, entitled '*A contribution to the Geology and Natural History of Nottinghamshire*,' pp. 21-23.

diameter, and it is probable that these blocks have fallen from a concealed cliff of the sandstone against which the Bunter may here be banked, as there is a quarry at a slightly higher level only 250 yards farther east which is entirely in a similar Carboniferous sandstone. It is impressive in this area to see how the ever-persistent agencies of denudation are resuming their arrested task of slow destruction as the long-sheltered surface of Triassic times is gradually being brought once more under their influence.

The prevalent tint of the Pebble Beds in the Nottingham district is pale yellow or buff, though in the 'Forest' country of North Nottinghamshire it is more generally a dull red. In its highest portion, however, in both districts, the rock is often nearly white—contains many pebbles, among which small nut-like pebbles of white vein-quartz are conspicuously abundant—and is in places indurated at the top by the segregation of a calcareous or, as already mentioned, of a barium cement. From these and other considerations arose the proposition of Shipman, above referred to, that this part of the series should be separated from the Bunter and regarded as a basement-conglomerate of the Keuper. The view was adopted by Aveline on the second edition of the Old Series geological map, quarter-sheet 71 NE., and in the accompanying memoir published in 1880; but it was controverted by Blake¹ and others, and was found to be impracticable in the recent re-survey of the ground. The question has been discussed in the lately published memoirs accompanying the New Series maps, sheets 125 and 126 ('Geology of the Southern part of the Derbyshire and Nottinghamshire Coalfield,' p. 126; and 'Geology of the Country between Newark and Nottingham,' 1908, pp. 36–7). It is unnecessary here to repeat the argument further than to state that all the essential features of the Bunter deposits are represented in the portions which Shipman assigned to the Keuper, and that the only distinguishable and natural base-line for the latter division occurs above them.

The junction of the two divisions was recently exposed very clearly in an excavation at Sneinton, which showed the following section (Fig. 6), reproduced from the 'Newark and Nottingham' memoir. The beds Nos. 2 to 5 of this section would doubtless have been included by Shipman in his 'Keuper Basement Beds.'

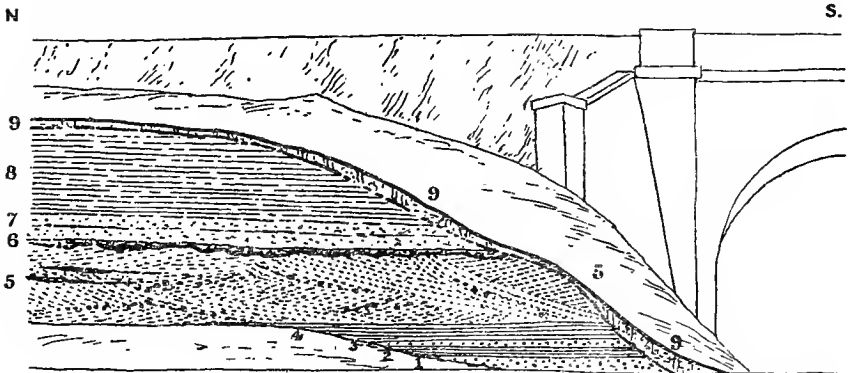
The bands of red and green marl, numbered 2 and 4 in this section, are thicker and more regular than are generally seen in outcrops of the Pebble Beds. We know, however, from the evidence of deep borings that such beds are not infrequent in the series; moreover, in the 'Forest' country north of the present map they may occasionally be traced for short distances at the surface, though with difficulty owing to their being so readily disintegrated. Like the smaller lenticles in the overlying sands, No. 5, they appear to represent the fine sediment deposited by stagnant muddy waters in small irregular basins among the ancient sand-banks during dry intervals between the floods. Frequently they have been partly cut away by the next flood and their indurated mud broken up

¹ J. F. Blake, 'Report of Excursion to Nottingham,' *Proc. Geol. Assoc.*, vol. xii., 1892, p. 126; and 'Geology' in 'A History of the County of Nottinghamshire,' vol. i., 1906, pp. 24–27, *Victoria History of the Counties of England*.

and scattered in lumps and pellets among sand and pebbles, as is illustrated in the present example. The only traces of contemporaneous organisms as yet recognized in the Bunter of Nottinghamshire are some fragments of plants referable to *Schizoneura*, found by Mr. R. D. Vernon¹ in the broken strings of marl in bed No. 5 of the above section.

The thickness of the Pebble Beds in the northern part of the map is about 350 ft., diminishing to about 220 ft. at Nottingham. Where buried under the Keuper, south of the Treut, the thickness of the entire Bunter (the two subdivisions not being recognized) has been proved by borings (*see* Folding-plate) to be 255 ft. at Edwalton and 221 ft. at Ruddington, showing the further thinning in this direction. North-eastward from Nottingham the formation as a whole becomes thicker, being 385 ft. at Gedling, 429 ft. at Woodborough, and 494 ft. at Thurgarton.

FIG. 6.—SECTION ON W. SIDE OF GREAT NORTHERN RAILWAY BRIDGE,
COLWICK ROAD, SNEINTON, SHOWING JUNCTION OF KEUPER AND BUNTER.



		Ft.	In.
Keuper Water- stones.	{ 9. Weathered clayey loam soil and downwash, the latter increasing to 5 ft. in thickness on the lower slopes, average ...	1	6
	{ 8. Regularly-bedded red and grey marl, with thin sandy partings increasing in frequency downward ...	10	0
	{ 7. Greenish-yellow flaggy sand-rock, with black streaks, evenly bedded, resting with sharp contrast on the current-bedded Bunter	3	0
Keuper Base- ment Bed.	{ 6. Lenticular seam of red marl and grit with small pebbles, chiefly quartz	2 in. to	1 0
	{ 5. Grey and greenish sand and sand-rock, strongly current-bedded, with small and large pebbles, both scattered and in bands and lenticles; also with impersistent streaks of red marl, 1 in. to 3 in. thick, containing traces of plants, locally broken up and distributed in cakes and rolled lumps among the quartzite pebbles	10	0
Bunter Pebble Beds.	{ 4. Stratified red and greenish-grey marl, with a lenticle of brownish sand	3	0
	{ 3. Pinkish-grey sand-rock	6 in. to	0 10
	{ 2. Stratified deep red and greenish-grey marl ...	10 in. to	1 0
	{ 1. Coarse pebbly sand-rock (normal Bunter Pebble Beds), exposed only in the road to the cutting	3	0

¹ 'On the occurrence of *Schizoneura paradoxa*, Schimper and Mougeot, in the Bunter of Nottingham,' *Proc. Cambridge Phil. Soc.*, vol. xv. (1910), pp. 401-5.

The Bunter, especially the Pebble Beds which occupy by far the greater part of its area, affords an unrivalled source of water-supply, due to its capacity for absorbing and storing the rainfall over its broad outcrop, and to its permeability which allows the underground waters to be copiously drawn from deep wells in the formation. The general insolubility of its constituents combined with their special properties as a filtering medium likewise ensures a high standard of purity in the water. Hence it serves as a reservoir for all the towns on or within reach of its outcrop, including Nottingham, Mansfield, Newark, Retford and many smaller places; and, recently, Lincoln also has been constrained to draw supplies from it.

Owing to this absorbent capacity there is very little surface drainage in the Bunter area, though numerous springs break out along its base and on low ground at its top where the easterly dip carries it beneath the impervious Keuper and the pent-up waters escape, as it were, over the tilted lip. The few streams which cross it have mostly their source in the springs or in surface-drainage flowing from the impervious formations on the eastward and westward.

Nevertheless the Bunter country is everywhere characterized by ramifying valley-systems, clearly the result of erosion by running waters at some bygone period, but now all or nearly all permanently dry. In a subsequent chapter we shall glance at the former conditions which these dry valleys indicate.

KEUPER.

In superficial extent of outcrop the Keuper ranks first among the formations of the map, occupying fully half its area if we include the tracts wherein it underlies the shallow valley-deposits and drift. It is separable into two subdivisions of very unequal thickness, the lower being the 'Waterstones,' ranging from about 100 ft. to 80 ft. or less, and the upper, the 'Keuper Marl,' averaging in this district about 700 ft. There is, however, no sharp distinction to be drawn between these subdivisions, for they merge indefinitely into each other; but the lower is characterized by the prevalence of thin flaggy sandstones, soft in texture and brown, deep red, or, more rarely, greyish in colour; while the Marl, as its name implies, is mainly composed of finer sediments of clayey consistency. Unlike the Bunter, the whole series is regularly and thinly bedded, having, indeed, frequently a laminated or shaly structure which implies its deposition in quiet waters. The presence of ripple-marking in many of the sandy bands; of veins of gypsum and casts (psedomorphs) of salt-crystals recurring at different horizons, and other indications, denote that these waters were shallow and probably subject to occasional desiccation. The transition from the torrential conditions of the Bunter to the quieter waters of the Keuper was in this district abrupt, and the fine sandy sediments of the Waterstones mark a stage of weak currents that became more feeble when the deposition of the Marl commenced. The general sequence of the Triassic rocks may imply the progressive sinking of an inland basin in a desert country, and its subsequent flooding to form a shallow salt-lake of fluctuating extent.

WATERSTONES.

The name attached to this subdivision of the Keuper is somewhat misleading in that it might be supposed to imply that the beds possess exceptional properties for the storage and supply of water, which in Nottinghamshire is certainly not the case. Though the sandy bands in the group do occasionally give rise to small springs, and generally yield a limited water-supply when penetrated by wells, the water is never very copious in quantity and is usually 'hard' in quality owing to an excess of mineral salts in solution; and while preferable in this respect to the almost waterless overlying Marl, it is in every way inferior to the Bunter as a water-bearing formation. The name was originally applied to the beds from a fancied resemblance of their ripple-marked laminated surfaces, often bright with mica-flakes, to 'watered silk.'¹ It is necessary, therefore, to bear in mind that the name of the formation is no indication that a good water-supply can be obtained from it—a caution which we have found to be sometimes needed.

At the base of the Waterstones in many places we find patches of hard conglomerate or coarse pebbly sandstone cemented by carbonate of lime, generally in lenticular masses, from an inch or two up to 2 ft. in thickness. This conglomerate where present forms a very definite basement bed to the Keuper, lying in hollows of the current-bedded Bunter sandrock and being surmounted by the fine-textured even-bedded Waterstones (*see* Fig. 6, p. 35). The character of this junction indicates that there may have been some erosion of the Bunter before the deposition of the Waterstones; and the fact that the Keuper is known to overlap the Bunter and to rest directly upon Palæozoic rocks in areas to the southward and westward of the present district, renders it the more probable that some degree of unconformity may here exist between the two main divisions of the Trias.

The character of the beds immediately above the conglomerate is shown in the last figure (Fig. 6, p. 35), the section represented being the best recent exposure of these strata in the district. Over 20 years ago, in the cutting of a sewage-tunnel through the same beds near Colwick Wood, 300 to 400 yds. farther eastward, the late E. Wilson, then curator of the Nottingham University Museum, obtained numerous remains of small fish, identified as *Semionotus* *sp.* and a palæoniscid species, from the basal layers of a band of greenish-yellow sandstone 10 inches thick, streaked with red and green marl; and he also found traces of a land-plant having the appearance of *Equisetites columnaris*.² This discovery is of peculiar interest as being the only known occurrence of undoubted fossils in the Keuper of the district, with the exception of a labyrinthodont footprint recorded by the Rev. A. Irving³ from the Waterstones of an adjacent cutting on the Midland railway. The fish-impressions were clustered thickly in a patch for about 30 ft., suggesting to

¹ *See* H. B. Woodward, 'The Geology of England and Wales,' 2nd ed., 1887, p. 227.

² E. T. Newton, 'On the remains of Fishes from the Keuper of Warwick and Nottingham,' *Quart. Journ. Geol. Soc.*, vol. xliii., 1887, pp. 537-40.

³ *Proc. Geol. Assoc.*, vol. iv., 1857, p. 73.

their discoverer that a shoal of fish had been entrapped in the shallows of a rapidly drying lake.¹

Above the beds shown in the Sneinton section, the lower part of the Waterstones is largely composed of bands of soft brown sandstone, from an inch or two to a foot or more in thickness, separated by comparatively thin partings of sandy micaceous marl or clay usually dull red in colour. But in the higher portion of the group, the shaly marls gain in thickness, and the sandstones are reduced to thin biscuit-like layers, until finally the beds assume the characters typical of the Keuper Marl. Under these conditions the line drawn on the map between the Waterstones and the Marl is necessarily more or less arbitrary, and may not always adhere strictly to the same horizon.

At their outcrop north and east of Nottingham the strata allotted to the Waterstones subdivision range between 80 and 100 ft. in thickness; but borings in the Trent valley show an increasing development of beds of this type north-eastward, which may result either from actually thickening or from the persistence of the sandy phase to a higher level in the Keuper. West of Nottingham the Waterstones are cut out for some distance by the Clifton Fault, but reappear, much diminished in thickness, in the Erewash valley around Stapleford and Sandiacre. They are seen again south of Dale, where there is a good section showing their junction with the Bunter in a big sand-pit 600 yds. NW. of Dale Church; a loosely compacted conglomerate or shingle-bed from 3 to 4 ft. thick here forms their base. The total thickness of the Waterstones in this quarter never exceeds 20 ft., and in some places they appear to have thinned out altogether.

The best exposures of the Waterstones near Nottingham are in the cuttings of the Midland railway between Sneinton and Colwick; in those of the Great Northern railway branch-lines between Daybrook and Gedling, and between Sherwood and Sneinton; and in the lower of the two quarries of the Bulwell Brick Co., The Wells Road, Nottingham. They are also visible in numerous small sections around the villages of Gedling and Carlton, and farther eastward, in the ravines or 'dumbles' of the small streams which drain the Keuper upland north of the Trent.

Gypsum is occasionally present in thin veins or strings in the Waterstones, but never so abundantly as at some horizons in the overlying Marl. The thin micaceous flags are often strikingly ripple-marked; and sun-cracked surfaces may at times be seen in them. Owing to the abundant admixture of fine-textured loamy or clayey material even among the more sandy bands, the predominant soils of the Waterstones are deep clayey loams, very different from the light sandy soils of the Bunter, and sometimes nearly as heavy as those of the Keuper Marl. The boundary between the Keuper and the Bunter is therefore always readily traceable by the soils, even where there is no exposure of the strata.

¹ While correcting the proofs of this memoir we were informed by Dr. H. H. Swinnerton, of the University College, Nottingham, that he had found another batch of fish-remains, in better preservation than those mentioned above, together with some reptilian footprints, in the Waterstones at Mapperley Park and other reptilian footprints in the same formation at Cockpit-Hill. Dr. Swinnerton has since published a preliminary note on his discovery in *Geol. Mag.*, dec. v., vol. ii., (May, 1910), p. 229.

KEUPER MARL.

From its superior thickness and breadth of outcrop the Keuper Marl is, everywhere in the Midlands, the most important subdivision of the Keuper. In the Nottingham district, while much thinner than in Cheshire and Staffordshire, its thickness is usually between 600 and 700 ft., diminishing irregularly south-westward as it approaches the Charnian axis of ancient rocks. The fine-textured sediments of which it is mainly composed have a very pronounced red colour, streaked and mottled with subsidiary bands of pale greenish-grey which are too thin to have any material effect upon the general redness that characterizes the Marl country. A narrow belt at the top of the Marl, however, is entirely of the greenish-grey tint, and, chiefly on this account, is recognized as a minor subdivision named the 'Tea-green Marl.'

Though of a clayey texture and always forming stiff clay-soils, the Marl in its ultimate composition is not chemically a clay, as its aluminous silicates are subordinate to its other constituents which consist mainly of siliceous silt or very fine-grained sand, along with carbonates of lime and magnesia in varying proportions. The following three analyses of Marls from different horizons at Nottingham and Newark, made in the Laboratory of the Survey and published in a previous memoir,¹ will serve to illustrate its composition.

Analyses of Keuper Marls.

288. Red Keuper Marl [near base of Keuper Marl], Mapperley, Nottingham.

289. Tea-green Marl [top of Keuper Marl], Beacon Hill Quarry, Newark.

290. Red Keuper Marl [near top of Keuper Marl], from the Vale of Belvoir and Newark Plaster Co's. Quarry, Bowbridge, near Newark.

Bulk Analysis.

	288.	289.	290.
SiO ₂	54.95	47.36	52.37
TiO ₂	.65	.60	.66
Al ₂ O ₃	15.54	15.05	13.72
Fe ₂ O ₃	3.27	2.71	4.04
FeO	1.44	1.94	1.37
MnO	trace.	trace.	trace.
(CoNi)O	nt. fd.	nt. fd.	trace.
CaO	3.78	5.90	5.09
MgO	5.11	6.24	5.92
K ₂ O	4.29	4.19	3.65
Na ₂ O	.37	.61	.86
Li ₂ O	trace	trace.	trace.
H ₂ O at 105° C.	2.80	2.21	1.87
H ₂ O above 105° C.	3.48	3.79	3.27
P ₂ O ₅	.15	.12	.10
FeS ₂	.09	1.27	.07
SO ₃	.06	.17	.12
CO ₂	4.30	8.55	7.49
Total	100.27	100.71	100.60

(Analyst, E. G. Radley.)

¹ 'The Melton Mowbray District,' &c., 1908, p. 100.

Where adequately exposed, the stratification of the Marl is always conspicuous, the bedding planes being in some parts so closely spaced that the rock displays a laminated or shaly structure, while in others it is more thickly bedded, the individual bands ranging up to a few feet in thickness and frequently exhibiting a massive aspect and a conchoidal or characteristically 'marly' fracture. The stratification is accentuated by the presence of the pale greenish streaks and bands which usually indicate a larger proportion of fine loamy sand or silt in the rock. These features are well seen in the photograph of a brickyard section near Nottingham reproduced in Plate VI.

The thin sandy bands are frequently indurated into hard ribs of fine-grained calcareous and dolomitic rock, known locally as 'skerry,' which can be raised in large irregular flagstones and was formerly much used for building, paving and road-mending in the Marl country. These 'skerry' bands are numerous in the lower half of the Marls but become more scanty in the higher part. The belts in which they occur persist for long distances, and as the hard rock in them resists the weather and gives rise to the definite surface features mentioned in our first chapter (p. 5), it is often possible to delineate their outcrop on the map and thus to bring out the stratigraphy of the Marl. Two belts, occurring respectively at about 50 ft. and about 100 ft. above the top of the Waterstones, are of particular consequence from their effect upon the outlines of the Marl country north of the Trent, and are indicated, so far as is practicable, on the one-inch map.

It has been suggested that the Keuper Marl may have been a loess-like deposit of wind-driven desert-dust, accumulated mainly on an old land-surface; but in Nottinghamshire its regular and persistent stratification, its even distribution, and indeed most of its characteristics, seem to prove that here, at any rate, it has been ultimately a water-borne sediment, whether carried into the quiet waters of the basin by winds or by streams.

The constant association of gypsum with the Keuper deposits has been already referred to. The mineral occurs here and there in crystalline veins and strings in almost every part of the formation, in the Waterstones as well as in the Keuper Marl; but its principal concentration in Nottinghamshire occurs at a definite horizon in the upper part of the Marls, where it is sufficiently abundant to afford the basis of an important industry. At Newark, a centre of the industry, the main gypsiferous belt comprises about 60 ft. of strata near the top of the red marls, its upper limits approaching within a few feet of the bottom of the Tea-green Marl. The same belt is prolonged into our district and is worked extensively at Cropwell Bishop (near the SE. margin of our map) by two companies, the Gotham Plaster Co., and the Snaith Plaster and Cement Co. The following section in the open pit of the latter will serve to show the general characters of the belt; the top of the section is about 20 ft. below the Tea-green Marl.



KEUPER MARL IN A BRICKYARD ADJOINING THE MIDLAND RAILWAY, HALF A MILE SOUTH OF
WEST BRIDGEFORD.

GYPSUM IN KEUPER MARL.

Section in the Gypsum pit of the Snaith Plaster and Cement Co., south of Cropwell Bishop.

	ft.	in.
Red marl, 1 ft. 4 in. ; and green marl, 3 ft. 6 in. ; with sporadic 'balls' or lens-shaped masses of gypsum ranging from 6 ft. to 14 ft. in horizontal diameter	...	4 10
Red marl, occasionally mottled green, with five or six beds of gypsum	...	30 6
Gypsum 'roof,' often stained blue-green, occasionally fibrous, and sometimes tailing off into thin string-like veins	...	1 3
Red marl	...	4 0
Gypsum 'floor,' with similar characters to the 'roof': up to	...	1 3
	about	42 0

In the south-western part of the map, along the margin of the Trent valley near Thrumpton, the principal deposit of gypsum lies at a slightly lower horizon in the Marls, and is worked in the neighbourhood of Gotham, just beyond the sheet-limits.

The layers of gypsum show great variation, often forming lens-shaped swellings and reticulate veins among the marl, and sometimes expanding and uniting to form large concretionary masses that frequently contain a core of anhydrite. Most of the gypsum in the thicker beds is pure white and of saccharoidal texture ; but the thinner veins usually have a fibrous crystalline structure and are translucent, this variety being the common form at the lower horizons where the mineral is less abundant. The substance is obtained mainly for the manufacture of fine plaster, while the translucent variety known as 'satinstone' is used to some extent for making beads and other ornaments, having been dug for this purpose especially at East Bridgford.

The gypsum is believed to have been originally deposited as a chemical precipitate from the evaporating waters of the inland basin, which became supercharged with mineral matter in solution. There has probably, however, been much recrystallization and concentration of the sulphate of lime since it was first precipitated.

The pale green or greyish Tea-green Marl at the top of the Keuper is about 20 ft. thick in the portion of its outcrop which falls within the map. Except in colour it does not differ much from the rest of the Marl division, but is somewhat more homogeneous and less streaky, having a massive structure and conchoidal fracture in unweathered sections. The difference in colour is generally considered to be due to subsequent chemical change in its iron-salts. It occupies the lower slopes of the Rhætic-Lias escarpment, and was formerly classed with these formations instead of with the Keuper.

The best exposures of the Keuper Marl are in the numerous large brickyards in the eastern suburbs of Nottingham, which show sections ranging up to 50 or 60 ft. in depth. Other good brickyard sections occur south of the Trent between West Bridgford and Edwalton (Pl. VI), and near Radcliffe-on-Trent ; and there is another section of the same kind at Chilwell, 4 miles

SW. of Nottingham, in which a fault is revealed, bringing marl into juxtaposition with some flaggy Keuper sandstones of unusual thickness. Many smaller artificial exposures occur at intervals along the outcrop; along with natural sections in the steep bluffs of the Trent north of East Bridgford; at Radcliffe; Clifton Grove; and south of Trent Railway Junction. The streams of the eastern upland north of the Trent likewise reveal numerous small sections in the banks and bottoms of their 'dumbles.'

The absence of fossils detracts from the interest of the formation to the student; but the ripple-marks, the 'sun-cracks,' the sharp and often perfect casts of salt crystals, with other curious markings often displayed on the surfaces of the thin hard skerries, are well worth attention; and the problems involved in the sedimentation of the thick and widespread mass of the Marls are many, and as yet are only partly solved.

RHÆTIC.

It has already been mentioned that this series, now regarded as the upper subdivision of the Triassic system, was formerly classed with the Lias as the lowest part of the Jurassic system. In fact, lithologically and stratigraphically the Rhætic Beds of the Midlands are more closely allied with the overlying Lias than with the underlying Keuper, so that the present classification is less in accordance with the local conditions than was the older scheme. It is based, however, on broader principles, and, as happens frequently in the established schemes of geological classification, general considerations must be allowed to outweigh local expediency.

Wherever the base of the Rhætic has been seen in Nottinghamshire it presents a sharp line of division from the Keuper Marl, with traces of slight erosion. There is some doubt whether the line marks an actual unconformity, the dip of both formations being in the same direction and at too low an angle to demonstrate unconformity if it should exist; but at the most the discordance can be only small. Upward, the Rhætic beds are strictly conformable to the Lower Lias, and the division between them is more or less arbitrary.

The series contains fossils—individually numerous but representing a limited range of species—chiefly bivalve shells (lamellibranchs) of small size, and fragmentary remains of fish and reptiles. Though assignable to marine forms, the shells by their dwarfed and peculiar types suggest that the conditions were somewhat unfavourable, and it is not until the Lower Lias is reached that a full and varied exhibition of marine life is found. The Rhætic therefore is interpreted as marking the first inroads of the sea upon the region in which Keuper conditions had until then prevailed.

The shells are mostly represented by casts only, so that their accurate determination is difficult. The common forms are: oval-shaped lamellibranchs (generically doubtful) resembling Moore's *Axius depressus*; *Myophoria? cloacina* (Moore); *Schizodus? concentricus* (Moore); *Modiola minima* J. Sow.; *Protocardia rhaetica* (Merian); *Pteria contorta* (Portl.) [= *Avicula contorta*

Auctt.]; "*Pullastra*" *arenicola* Strickl.; and a few others. The fragmentary fish-remains, which occur principally in a thin and impersistent 'bone-bed' at or near the base of the series, are referable to species of the genera, *Acrodus*; *Ceratodus*; *Gyrolepis*; *Hybodus*; *Nemacanthus*; and *Saurichthys*; together with the teeth, vertebræ, &c. of *Ichthyosaurus* and other reptiles.

The Rhætic group is divided by lithological characters into two subdivisions, but these are too thin to be shown separately on the map, the entire series having an average thickness of little more than 30 ft. The lower subdivision, known as the *Avicula-contorta* Shales, consists of black thinly laminated shales (generally very fossiliferous) and occasional sandy layers, with the basal bone-bed of sandy or earthy texture, sometimes containing small quartz pebbles. The thickness of the *Avicula-contorta* Shales averages about 15 ft.

The upper subdivision is composed of beds of light bluish-grey marl interbedded with a few thin bands of compact argillaceous limestone, usually more or less nodular and disconnected. It has been usual in the Midlands to regard this subdivision as equivalent to the 'White Lias' of the south-west of England, but the correlation has recently been challenged,¹ and it is perhaps advisable to discontinue the use of this term and to substitute 'Upper Rhætic' for it. One of the limestone-bands, a fine-grained hard splintery rock formerly much used for road-mending, affords a convenient upper boundary to the series, the conformable beds above it being classed as Lower Lias. Fossils occur more sparingly in the Upper Rhætic than in the black shales, but are present here and there both in the marly bands and in the limestones. The thickness of the subdivision in this district is about 18 ft.

The outcrop of the Rhætic beds, as shown by the map, occupies a narrow belt on the upper slopes of the sharp escarpment which bounds the Liassic area in the south-eastern part of our district. It is buried under Glacial drift around Clipston and Stanton, but elsewhere is easy of recognition by the shape of the ground and by the character of the soil. Exposures are, however, small and scanty, and our knowledge of the sequence has been obtained chiefly from the better sections farther to the north-east, at Barnstone and Newark,² and to the south-west near East Leake and Barrow.³ The following sections, observed during the recent survey by Mr. B. Smith and reproduced from the Sheet Memoir,⁴ will serve to show the character of the upper subdivision.

¹ See L. Richardson, 'The Rhætic Section at Wigston, Leicestershire,' *Geol. Mag.*, dec. v., vol. vi., 1909, pp. 366-70

² See 'The Country between Newark and Nottingham,' *Mem. Geol. Surv.*, 1908, pp. 54-8; also E. Wilson, 'The Rhætics of Nottinghamshire,' *Quart. Journ. Geol. Soc.*, vol. xxxviii., 1882, pp. 451-6.

³ See 'The Country between Derby, etc., and Loughborough,' *Mem. Geol. Surv.*, 1905, pp. 35-6; also M. Browne, *Report British Association* for 1895, p. 689.

⁴ 'The Melton Mowbray District and S.E. Nottinghamshire,' Sheet 142, 1909, pp. 18-20.

On the north-east side of Cotgrave Gorse occurs a small stone-pit showing the junction of the Rhætic with the Lower Lias, as under :—

		ft. ins.
	Soil, with irregular pockets and 'pipes' of red sand ...	6+
LOWER LIAS.	Two thin bands of pale yellowish limestone and shale : spines of echinoderms in the limestone ...	4 0
	Band of blue limestone with shelly layers ...	7
	Shale... ..	1 3
UPPER RHÆTIC	Compact fine-grained limestone; blue hearted, with purplish exterior; splitting with conchoidal fracture	1 0
		7 4

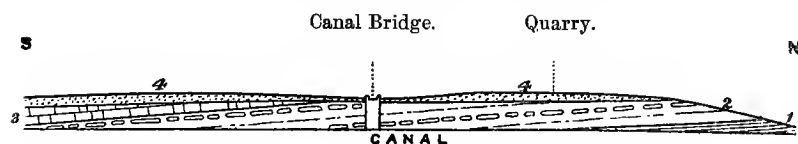
A deeper section in the beds at a slightly lower horizon is revealed in a quarry to obtain clay for puddling, on the left bank of the Grantham Canal at Blue Hill, where the following sequence was measured :—

		ft. ins.
	Made ground	4 0
	Brown soil with stones	6
UPPER RHÆTIC	Thin band of purple-blue rather crystalline limestone with <i>Modiola minima</i> J. Sow	4
	Blue-brown calcareous shales with 'race'	1 0
	Band of thin concretionary limestone	1
	Yellowish creamy calcareous shales with 'race'	9
	Creamy fine-grained concretionary limestone	2½-5
	Calcareous shales	9
	Nodular creamy blue-hearted limestone	3-6
	Blue-yellow calcareous shales, stained red	1 0
	Fine-grained creamy and blue-hearted septarian lime- stone, passing laterally into shales. Pink-purple staining outside. Manganese (dendritic) markings...	6
	Grey-blue clays and marls, stained brown and red ...	2 0
	Blue-grey somewhat concretionary clays and marls with manganese stains, gypsum crystals, and fossils ...	7 0
	Black fossiliferous shales at water level; weathered yellow on bedding planes; containing " <i>Pullastra</i> " <i>arenicola</i> Strickl., and <i>Schizodus? concentricus?</i> (Moore)	1 0
		19 6

The canal-cutting of which the above section forms part has crossed all the strata from the top of the Keuper (Tea-green Marl) to the Hydraulic Limestones of the Lower Lias, but except at the quarry is now much obscured. The following generalised section has been constructed from the evidence still available.

FIG. 7.—SECTION THROUGH THE RHÆTIC ESCARPMENT AT BLUE HILL, NOTTINGHAM AND GRANTHAM CANAL. (B. Smith.)

Length of section, 220 yds. Vertical scale, about 2 × horizontal il.



4. Made ground. 3. Lias shales and limestones. 2. Shales and marls, with concretionary limestones (Upper Rhætic). 1. Black fossiliferous Rhætic shales,

At the northern end, in the quarry, the dip is about 3° in the line of section. South of the quarry the Lias Limestones come on, well bedded and fossiliferous. North of the landing-stage they rest on a few feet of shale, below which are blue marls associated with nodular masses of compact fine-grained limestone showing a conchoidal fracture. These marls with nodular limestone represent the top part of the Rhætic, not seen in the quarry, and they add about 4 ft. to the thickness given in the previous section, making about 17 ft. in all. The marls are often contorted and compressed laterally; they enclose small nodules of limestone and irregular hollow lumps of calcareous 'race,' and when weathered contain numerous small crystals of gypsum.

A good section in the black shales forming the lower subdivision of the Rhætic was laid open in the cutting and tunnel of the Midland railway at Stanton-on-the-Wolds. It is now obscured, but was studied during the construction by Wilson, who published the following details of it¹:—

		ft. ins.
(RHÆTIC).	"Boulder-clay with local intercalations of drift-sand 50 ft. to	60 0
	{ Shales dark coloured, thickly laminated, with a few thin seams of sandstone and a band of nodular limestone 1 ft. 9 in. from base: <i>Cussianella contorta</i> , <i>Axinus elongatus</i> , <i>Protocardium Philippianum</i> ...	6 0
	{ Pyritic sandstone $\frac{1}{2}$ in. to	2 $\frac{1}{2}$
	{ Shales darker and more thinly laminated than the overlying, with occasional streaks of fine white sand: <i>C. contorta</i> , <i>A. elongatus</i> , <i>P. Philippianum</i> ...	3 0
	{ Pyritic limestone, with <i>A. elongatus</i> , <i>Modiola minima</i> , fish scales, sun-cracks $\frac{1}{2}$ in. to	1
	{ Shales black, fissile, with thin streaks of fine grey sand 9 in. to	10
	{ Bone-bed or coprolite seam, soft white sand and quartz-pebbles: spines of <i>Nemacanthus filifer</i> , and <i>Hybodus</i> , sp.; teeth and scales of <i>Saurichthys acuminatus</i> , <i>Hybodus minor</i> , <i>H. reticulatus</i> , <i>Hybodus</i> sp., <i>Acrodus minimus</i> , <i>Sargodon tomicus</i> , <i>Ceratodus altus</i> , <i>Gyrolepis tenuistriata</i> , and various cestracient palatal teeth; teeth and coprolites of <i>Ichthyosaurus platygodon</i> , <i>Ichthyosaurus</i> sp., and other reptilian and piscine teeth, vertebræ, bones and coprolites ...	1
	{ Shales black, fissile, and earthy layers alternating ...	1 4
	{ Coprolite-seam, earthy; coprolites at wide intervals ...	1
	{ Shales black, laminated, with occasional reptilian bones	1 3
	{ Tea-green Marls (UPPER KEUPER). Light-blue marls weathering yellowish-green and breaking up into cuboidal fragments; base not seen	20 0
	The Upper Rhætic marls were not seen <i>in situ</i> ; but limestone nodules with <i>Estherie</i> were found in the overlying drift."	

¹ 'The Rhætics of Nottinghamshire,' *Quart. Journ. Geol. Soc.*, vol. xxxviii., 1882, p. 454.

CHAPTER V.

LOWER LIAS.

INTRODUCTION.

The transgression of the sea upon the enclosed basins and desert lands of the Trias, which began in Rhætic times, went on with increased vigour in the subsequent period during which the Liassic sediments were deposited. The fossils preserved in these sediments are all characteristically marine, save for an occasional remnant of plant-life from the land. They indicate an open sea of some little depth, sufficiently distant from the coast to be beyond the reach of coarse detritus, yet sufficiently near to receive a constant accession of the finer products of land-waste.

When the sedimentation was copious and persistent, thick beds of stratified mud were accumulated—now consolidated into shales; when it was for a time scanty, the sediment was incorporated with much calcareous matter from the decay of shells and other relics of lime-secreting organisms, giving rise to the bands of impure limestone that are intercalated with the shales.

It is probable that the Lias originally extended over and far beyond the area of our map. Prolonged erosion has, however, stripped back the formation until it now covers only about 12 sq. miles in the south-eastern corner of our district, under conditions which illustrate very clearly the progressive reduction of the outcrop by the wearing back of the escarpment and by the stream-channelling of the inner tract.

Of the three main divisions of the Lias in the Midlands, the Lower Lias is by far the thickest, reaching about 650–700 ft. where it occurs in its entirety in the country east and south-east of our district. But of this thickness only the lowest 100 ft. or so is represented in the area of the map, so that this portion alone will need particular notice in the present memoir. The Lower Lias is subdivided into seven or more fossil-zones based on the occurrence of successive forms of ammonites. The strata with which we have now to deal belong in part to the lowest zone, viz., that of *Psiloceras planorbis*, and in part to the next higher zone, that of *Schlotheimia angulata*; but it is possible that a small portion of the succeeding zone of *Coroniceras bucklandi* (which is inseparable in the neighbouring districts from the preceding zone) may be present beneath the boulder-clay of Kinoulton Wolds.

The *Psil. planorbis* Beds possess distinctive lithological characters, as indicated in the term 'The Hydraulic Limestone Series,' under which we shall here describe them.

HYDRAULIC LIMESTONE SERIES.

These beds follow conformably upon the Upper Rhætic stage and there is no conspicuous difference of composition to mark the junction. They consist of bluish-grey laminated shales with numerous intercalated bands of paler flaggy argillaceous limestone. The series is quarried on a large scale for the manufacture of cement and other purposes at many places along its outcrop, particularly around Barrow-upon-Soar (in Sheet 142); at Barnstone (in Sheet 126); and in the neighbourhood of Owthorpe, the last-named locality alone falling within the present map. The thickness of the division in our district is about 20 ft. Its outcrop, usually not more than half a mile wide, attains the exceptional width of nearly 3 miles on the gentle dip-slope between Cropwell Bishop and Kinoulton, owing in part to the combination of slight undulations with a very low average dip.

Though not so rich in fossils as some of the higher zones of the Lower Lias, the beds contain a distinctive marine fauna, including the zonal ammonite, *Psiloceras planorbis* (J. Sow.), with *Caloceras johnstoni* (J. Sow.) in the upper part of the zone; several lamellibranchs, among which are *Lima gigantea* (J. Sow.) and other species, *Modiola minima* J. Sow., *Ostrea irregularis* Muenst., *O. liassica* Strickl., *Pecten* sp., *Pleuromya crowcombeia* Tate, and other forms; with spines and other relics of echinoderms, including *Cidaris edwardsi* Wright. But the particular interest of the series to the palæontologist lies in the numerous and varied remains of saurians and fish which have been unearthed during the long-continued excavations for the cement industry and now grace many of our public museums. Among the reptilian remains, *Ichthyosaurus* and *Plesiosaurus* are represented by several species; and the fish, by species of the genera *Dapedius*, *Ptycholepis*, *Oxygnathus*, &c.¹

The best exposure of the Hydraulic Limestone Series actually within our area is afforded by the previously-mentioned pits north-east of Owthorpe, while the more extensive sections at Barrow and Barnstone are also easily accessible to the student. At Owthorpe the stone is raised for lime-burning and for paving-flags, building, &c. The following section was visible in 1906 in the larger quarry on the east side of the road N.E. of Owthorpe, 300 yards S. of the inn marked on the map. The words in square brackets are the names given by the workmen to the different bands of stone. The 'spine-bed,' crowded with small spines of echinoderms, is a well-marked horizon in this district, traceable over 2 square miles and ranging up to an inch in thickness. Most of the characteristic invertebrate fossils mentioned above may be found in this and neighbouring sections.

¹ A full catalogue of these and other fossils of the Lias in the Leicestershire district is given by C. Fox-Strangways in his memoir, 'The Country near Leicester,' (Sheet 156), *Mem. Geol. Surv.*, 1903, pp. 95-115: see also M. Browne, 'The Vertebrate Animals of Leicestershire and Rutland,' 1889, Leicester.

	Ft
Soil with a few pebbles of sandstone	1
Friable limestone, weathered yellow, with <i>Psiloceras planorbis</i> ...	}
Shales	
Limestone, weathered yellow, with $\frac{1}{2}$ in. 'spine-bed' [Rust] at top. <i>Psil. planorbis</i>	}
Shales	
Pale nodular limestone, with <i>Psil. planorbis</i>	}
Shales	
Pale nodular limestone } [Twin floors]	}
Shales	
Pale nodular limestone }	}
Shales	
Blue wavy-banded limestone [Thick floor] in two beds, with <i>Ichthyosaurus</i>	2
	2
	—
	About 11 ft.

Water-level was reached at the above depth, but we were informed that the section continued as under :—

Blue limestone [Cap], with *Plesiosaurus*.

Blue flaggy limestone [Slab].

do. [Bottom].

There are numerous small exposures of the Hydraulic Limestones in the beds of the streams near Colston Basset, and in old pits from which the stone was formerly dug. Traces of old excavations are visible at intervals in many other parts of the outcrop, particularly in the vicinity of the Grantham Canal, but the sections are in most cases obliterated. Where seen, the strata are similar to those of the Owthorpe pits.

From the escarpment, in which they protect the underlying Rhætic beds, the Hydraulic Limestones descend gently with a long dip-slope toward the broad depression which constitutes the Vale of Belvoir. This low ground is based on clays, with fewer sustaining stone-bands, belonging to the zone of *Schlotheimia angulata* and to higher zones of similar composition. The streams draining the depression flow northward to the Trent, breaking across the rim formed by the Hydraulic Limestones in steep little valleys, of which the valley of the Smite at Colston Basset is an example.

CLAYS OF THE SCHLOTHEIMIA ANGULATA ZONE.

The beds above the Hydraulic Limestones are very sparingly exposed in our map, so that our account of them must be based partly upon information obtained from districts beyond its border. They consist of dark blue shaly fossiliferous clays containing impersistent bands and nodules of limestone. These beds probably do not attain a thickness of more than 70 or 80 feet in the part of their outcrop which falls within the map, but the type is prolonged southward to a total thickness of about 200 feet. They occupy the low ridge on which Kinoulton stands, and were formerly dug at this place for brickmaking, but the section is now obliterated. They crop out from beneath the boulder-clay along its steep edge on both sides of the Wolds from Kinoulton Wolds to Mount Pleasant, but the only exposures are in shallow ditches and ponds. A few fossils may usually be obtained from the fragments and

nodules of limestone occurring along the outcrop, and the beds would no doubt yield many species if some better opportunity for collecting were available. *Cardinia listeri* (J. Sow.), *Lima gigantea* (J. Sow.), *Lima hettangiensis* Terq., *Pecten* sp., and fragments of ammonites (*Schlotheimia*?) are among the fossils which we collected from the outcrop in the neighbourhood of Owthorpe.

The higher subdivisions of the Lower Lias, developed in the country to the south and east of our limits, have been described in the recently-published memoir on Sheet 142 (Melton Mowbray), to which we may refer the reader who desires information respecting the complete sequence.

CHAPTER VI.

GLACIAL DEPOSITS.

INTRODUCTION.

It is generally accepted by geologists that the boulder-clays with their associated sands and gravels by which the 'solid' rocks are covered in many parts of our Islands were accumulated under conditions similar to those which now prevail in Arctic regions. Though there is still some difference of opinion as to the precise method of their deposition, the theory currently held is that they are mainly the product of great ice-sheets which crept slowly over the land. Among the distinguishing features of Glacial deposits are the presence of boulders transported from distant sources, and of peculiar striations on the boulders and sometimes also on the rock-floor upon which the deposits rest. In the present district these features are best exemplified in the Boulder Clay of the plateau between Keyworth and Kinoulton (p. 52).

There can be little doubt that the Glacial deposits were originally more extensive in the district than we now find them, and that they have been much reduced in area by later erosion. The composition and situation of the patches which remain imply that at least the greater part, and probably the whole, of the country shown in the map had at one time or another its mantle of land-ice. Apparently, however, its glaciation was neither so prolonged nor so severe as that of the north-eastern and north-western parts of England in the same latitudes. Lying almost equidistant from the main reservoirs of ice situated respectively to the north-east and north-west, it seems to have been temporarily invaded by an overflow from both quarters. Thus in the scanty patches of drift on eminences on both sides of the Leen valley, in the northern part of the map, boulders are occasionally found, which are recognizable as having been derived from the Lake District, like the similar boulders that are abundant in the drifts of Cheshire and Lancashire. Such boulders have evidently been carried into the district from the north-west. On the other hand, the boulder-clay of the plateau in the southern part of the map is merely a prolongation of the great sheet of Chalky Boulder Clay which spreads south and south-eastward over great stretches of country, and contains clear evidence of its derivation from strata lying to north-eastward or ENE. The time-relations of these different drifts to each other are obscure, and have been variably interpreted, a matter to which we shall presently revert. The whole of the tract occupied by the Carboniferous rocks in the basin of the Erewash River is devoid of drift, unless the sprinkling of pebbles, mainly derived from the Bunter, on the eastern side of the basin and in one or two isolated spots on the western side, south of Heanor, be the distributed relics of Glacial gravels. Similarly, on the upland of Keuper Marl east of Nottingham and north of the Trent, there is no foreign material, except a few pebbles in the soil and at the base of the alluvium in some of the little valleys.

Even in the Trent valley itself, we have been unable to detect any deposit which could be recognized with confidence as the product of the great ice-sheets, though some of its older gravels bear evidence to the former presence of floe-ice in the river. In every case that we have been able to examine, where the gravels of the valley have been pierced for foundations, wells, &c., they have been found to rest directly upon Triassic strata, and, judging from the samples we have seen, the 'stony clay' sometimes mentioned as occurring at the base of the gravels appears to represent merely the letting down of a few pebbles into the underlying Keuper Marl. If any true boulder-clay were ever deposited within the valley, it has either been entirely removed by later erosion, or its remnants lie hidden beneath the river-deposits in places which have not yet been open to investigation. The point is of much consequence in its bearing upon the question whether the Trent in this portion of its course occupies a pre-Glacial valley or whether its present trench has been eroded since the glaciation of the country. Until a wider field of research has been covered, this question cannot be positively answered, but we shall have some suggestions to offer upon it (pp. 54, 56-7).

BOULDER CLAY AND GLACIAL GRAVELS.

Of the isolated patches of drift along the margins of the Leen valley above referred to, the most conspicuous on the map is that which caps the ridge between Long Hill and Misk Hill, west of Hucknall Torkard, on the watershed between the Erewash and Leen valleys. It consists of a thin deposit of whitish clay with few stones, overlying an impersistent bed of sand and gravel, the whole not more than a few feet in thickness. Along the foot of the ridge on the southern side lie several large boulders of Lake District rocks, including one of andesitic ash 24 cubic feet in content.

On the Magnesian Limestone south and south-west of Hucknall Torkard there are numerous small patches of gravelly drift, ranging up to 10 feet in thickness, only the larger of which are shown on the map. These generally form knolls rising slightly above the surrounding country, probably due in part to the original moundiness of the deposit, and in part to the more rapid lowering of adjacent ground not thus protected from erosion.

On the eastern side of the Leen valley, along the outcrop of the Bunter formation, the hill-tops have usually a gravelly capping; but as the disintegration of the Bunter Pebble Beds themselves gives rise to a concentration of the heavier pebbles at the surface in such positions, and as the gravels are always composed principally of this Bunter material, it is difficult to tell how much of the gravel is Glacial drift and how much is merely a later residue from the Bunter.

In a few places, however, where gravel pits have been opened, the Glacial origin of the deposit is proved by its structural characters and by the presence of boulders of Carboniferous sandstone, Lake District volcanic rocks, &c. This gravelly drift occurs in patches at an altitude of over 400 feet above O.D. in Bestwood Park and descends to lower levels southward. There are indications that it may be the remnants of a once extensive fluvio-glacial

fringe thrown down by torrents along the retreating margin of the north-western ice-sheet. At lower levels, sections of similar gravel with boulders are visible in several places between Bulwell and Nottingham, on the crest of slopes rising 40 or 50 feet above the bottom of the Leen valley.¹

That the surface-features of the country have been greatly modified since the drift was deposited is further indicated by the position of some of the high-lying gravel in relation to the present valley of the Trent. Thus, a small patch of gravel from three to five feet thick, now mostly dug and removed, occurred on the very crest of the Trent bluff at Colwick Wood, east of Nottingham, at 300 feet above O.D., or 225 feet above the river-flat, and seems to have been deposited before the excavation of the trench. Again, south of the river, the top of Wilford Hill, a mile S. of West Bridgford, at 284 feet above O.D., is capped with confusedly intermingled and contorted sand, loam, and gravel, made up principally of material derived from the Bunter and from the Keuper on which the deposit rests. This drift was exposed to a depth of 10 or 11 feet in recent excavations for a reservoir.

In the gravels above described chalk-flints are either absent or very rare, though occasional flint-like fragments of Carboniferous chert are not uncommon. These gravels are thus differentiated from the gravels of the country to the southward in which flints are nearly always abundant. The latter gravels occur in patches capping risès of lower altitude around Plumtree, Ruddington and Clifton Pasture; and their relationship to the adjacent plateau of Boulder Clay suggests that they were derived from the receding margin of the north-eastern ice-sheet in the same way that the other gravels are supposed to have been derived from the north-western sheet.

As shown on the map, the main mass of Boulder Clay south of the Trent rests principally upon the Lias, though it overlaps the escarpment of the Rhætian at Clipston and completely buries it at Stanton-on-the-Wolds. At the southern margin of the map the plateau of Boulder Clay has a breadth of nearly three miles; then, contracting in breadth, it extends north for over three miles, to Cropwell Wolds, still forming the highest ground in the neighbourhood. Eastward it ends off abruptly in a very definite feature overlooking the Lower Lias plain, and on all sides it shows indications of having been much reduced in area by erosion. Where not furrowed by post-Glacial drainage-channels, the Boulder Clay has a smooth or very gently undulating surface, having levelled up the irregular features of the underlying solid formations. Hence its thickness is very variable, being of course deepest where it fills hollows of the old surface. One of these drift-filled hollows was intersected by the cuttings and tunnel of the Midland railway near Stanton-on-the-Wolds, revealing the section represented in Fig. 8. There is no longer any clear exposure in the cuttings and it is fortunate that they were examined and described

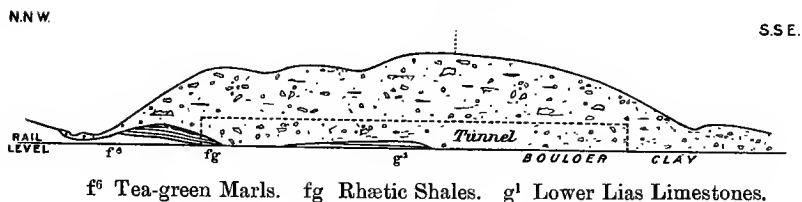
¹ For details see 'The County between Newark and Nottingham,' *Mem. Geol. Surv.*, 1908, pp. 69-70.

FIG. 8.—SECTION THROUGH THE STANTON TUNNEL ON THE MIDLAND RAILWAY.¹

(Reduced from the original copy in Mr. James Plant's MSS.)

Horizontal Scale, 3 ins. = 1 mile. Vertical Scale, 160 ft. = 1 in.

Public Road.



when fresh by Dr. Teall and other observers.² The record of the occurrence of glacial striæ on the Lias limestone at the base of the drift in the tunnel is of particular consequence, as such occurrences are extremely rare in the Midlands owing to the generally unsuitable character of the rocks for receiving or retaining striæ. The direction of ice-movement thus indicated is from north-east to south-west. The only other known example of a striated rock-surface anywhere in the surrounding country is at an ironstone quarry near Wartnaby, 6 miles S.E. of Stanton tunnel, where the scratches had an average direction of N. 15° W. to S. 15° E.³ In both cases the striations point to the flow of ice over the tract of country now devoid of drift, implying either that there has been great erosion of this tract since Glacial times or that the original deposition of the drift was very partial and local. Both causes have probably operated in bringing about the present result; but it is obvious, from the vast amount of transported material incorporated in the Boulder Clay of the plateau, that the functions of the ice-sheet must have been destructive in some places, otherwise it could not have been constructive in others.

The composition of the Boulder Clay varies from place to place even within the small portion of its plateau compassed by our map. Around Clipston, and from Cropwell Wolds to Normanton Wolds, the clay is predominantly red in colour, like Keuper Marl, and its included stones are chiefly pebbles from the Bunter, clearly signifying its derivation from the Triassic rocks. Farther southward its matrix becomes dark purple or bluish, from an increasing admixture of material derived from the Rhætic and Lias. A few flints occur in the soil over the whole tract, but it is not until we reach Kinoultton Wolds, close to the edge of the map, that they become really numerous, and here the presence of much detritus from the Chalk and Oolites imparts a greyish aspect to the Boulder Clay and brings it to the normal condition of the Chalky Boulder Clay in the country farther south.

The lateral change in the composition of the Boulder Clay in this district is thus consistent with the other evidence in implying a general south-westerly flow of the ice-sheet and a dragging forward

¹ From 'Geology of the Melton Mowbray District, &c.' p. 78.² *ibid*, p. 77.³ *ibid*, p. 70.

of detritus from the different formations that lay in its path. But in the Wreak valley east of Melton Mowbray, and in other places to the southward where the drifts are very thick, they exhibit much variation and complexity in vertical section as well as horizontally, the typical Chalky Boulder Clay usually constituting only the upper part of the series, with variable sands, gravels, stony loams and laminated clays below, and a red boulder-clay at or near the base. The succession has been interpreted as implying three or more distinct periods of glaciation separated by as many interglacial periods during which the country was free from ice.¹ It appears to the present writer, however, that the facts do not warrant this interpretation, and that there is no satisfactory evidence in the district for the supposed interglacial episodes.² The differences of composition in the boulder-clays may be accounted for by slight changes in the direction of ice-movement during the progress of the glaciation, so that material from different quarters was brought to the same spot at successive times; and the stratified material intercalated with the boulder-clays is of the character that we should expect to find in the flood-sifted detritus of the ice-sheets. The general tenour of the evidence seems to denote that during some part of the Glacial period the north-western and north-eastern ice-sheets were coalescent in our district around the tract now occupied by the Trent valley, but that at other times they were separated by the recession of their respective borders, leaving an intervening area of bare land. The evidence suggests, moreover, that the maximum extension of the one sheet did not coincide in time with the maximum extension of the other, but that first the north-western ice was in the ascendancy and dominated the flow in our district, and that afterwards this sheet waned while the north-eastern sheet waxed and became the controlling factor of the movement in all the country east of the Trent. It may further be suggested here, as a working hypothesis based on the present state of our knowledge, that the Trent itself may have come into existence as a marginal river of the north-eastern ice-sheet during the later phases of the glaciation, when the north-western ice had shrunk back toward the northern watershed of the basin.

Leaving these theoretical matters, however, which cannot be fully discussed in this work, we will resume the actual description of the drifts.

The patches of drift shown on the map in the hilly belt of Keuper Marl between the Coal Measures of the Erewash basin and the Trent valley are mostly thin and of ill-defined character, being recognizable chiefly by the stony nature of the soil. The pebbles are mostly derived from the Bunter, with here and there the admixture of a few flints. Nevertheless, at Spondon, just outside the western edge of the map, there is a mass of Boulder Clay, which is reported in one spot to have a thickness of at least 60 feet,³ and contains a large amount of detritus from Carboniferous

¹ R. M. Deeley, 'The Pleistocene Succession in the Trent Basin,' *Quart. Journ. Geol. Soc.*, vol. xlii., 1886, pp. 437-80.

² See 'The Geology of the Country between Newark and Nottingham,' *Mem. Geol. Surv.*, 1908, pp. 73-4.

³ R. M. Deeley, *op. cit.*, p. 448.

rocks, showing that the district has been overswept by the north-western ice.

Although no drift is shown in the eastern part of the map on the lowland of Keuper Marl south of the Trent, there is often a sprinkling of pebbles of quartzite and flint, more or less intermingled with the weathered clay capping the red Marl, while sometimes the pebbles occur in 'pockets' 3 or 4 feet below the surface and are associated with small boulders of Carboniferous and other rocks. Material of this kind has been supposed to indicate a renewed glaciation in the valleys at a late stage of the Glacial period;¹ but we have been unable to find any facts demonstrating that it was formed by land-ice, nor does the general evidence sustain the view that there has been a separate period of valley-glaciation. The superficial detritus in question more probably represents the washings from Glacial deposits which have been destroyed and redistributed since the withdrawal of the ice-sheets, for it is clear that there has been severe erosion of the lower country since that time, and it is unlikely that its present surface was then in existence. The stony loam observed by Shipman in the valley of the Leen,² is probably a similar land-wash, like that in the valley of the Greet³ and in the small valleys near Barrow-upon-Soar,⁴ beyond the area of our map.

¹ E. M. Deeley, *op. cit.*, p. 471-9.

² 'Notes on the Alluvial and Drift Deposits of the Trent Valley near Nottingham,' *Ann. Rep. Notts. Nat. Soc.* for 1879, pp. 15-32.

³ 'The Country between Newark and Nottingham,' *Mem. Geol. Surv.*, 1908, p. 75.

⁴ 'The Melton Mowbray District' &c., *Mem. Geol. Surv.*, 1909, p. 85.

CHAPTER VII.

TRENT GRAVELS AND LATER ALLUVIAL DEPOSITS.

THE OLDER GRAVELS.

Along its whole course across the district the broad valley of the Trent is flooded with river-gravels, sometimes covered by alluvial deposits of finer texture, but often rising slightly above these later deposits in irregular tracts elongated in the direction of the valley. These gravels form the greater part of the river-flat and are hardly beyond the reach of the highest floods; but there is, besides, an older set which lines the sides of the valley here and there at higher levels and represents an earlier stage in its excavation. Where the distinction is clearly marked, the older River Gravel is specified on the map by a colour and symbol different from that of the newer River Gravel; but it is sometimes difficult to separate them, especially in the neighbourhood of the broad low tract around the confluences of the Derwent, Erewash and Soar with the Trent. The whole series was accumulated during a period when the river and its tributaries far exceeded their present volume and were much more powerful both in erosion and in transport. The gravels carry a record of the river from its establishment, or—supposing it to have had a precursor—from its re-establishment, at the waning stages of the great glaciation to the time when its capacity was abated nearly to its present dimensions. The persistent fall of both the older and newer gravels along the gradient of the present valley proves that, so far as this district is concerned, there has been no radical change in the drainage system since its initiation; and the presence of the remains of extinct Pleistocene mammalia, including the mammoth, rhinoceros and hippopotamus, in the gravels, is evidence of the antiquity of at least some part of them. It has indeed been urged by Mr. Deeley in his paper previously referred to¹ that the Older River Gravel was accumulated during a warm 'Interglacial' epoch which was followed by a renewal of glaciation in the valleys; but as stated in the last chapter (p. 55) we have been unable to find any definite evidence in support of this view, and it runs counter to the physiographical and stratigraphical conditions of the deposits in question. There is every probability, however, that the river began to deposit its gravels as soon as the shrinkage of the latest ice-sheet had left it an open course, and that land-ice may have lingered around some of its head-waters, while the Older Gravels were being accumulated. The coarseness of the material, the big boulders occasionally contained in it, and the disturbance which it has often undergone, point to the occurrence of torrential floods, carrying ice-floes, and filling the valley from side to side. Such conditions are likely to have obtained at the close of the

¹ 'The Pleistocene Succession in the Trent Basin,' *Quart. Journ. Geol. Soc.*, vol. xlii., 1886, pp. 437-480. Mr. Deeley's views have been frequently cited by glacialists in the general literature of the subject.

Glacial period, when not only was the land ridding itself of its icy accumulation but, in addition, the whole snowfall of the winter was released suddenly by the thaw of early summer. The ramifying dry valleys of the Bunter country, sculptured by a surface-drainage which no longer exists, are proof of the vast amount of detritus which has been passed down to the trunk-valleys since the great glaciation, and of the former vigour of all the rivers. They probably denote a stage when the frozen condition of the subsoil prevented the downward percolation of thaw-water and spring-rains into the otherwise permeable rocks.

West of Nottingham, the Older Gravels within our map lie entirely on the north side of the valley, extending in an eroded and much interrupted belt from Borrowash to Beeston. Some of the higher patches in the west lie at more than 50 feet above the present alluvial flat, while the old terrace on which the greater part of the town of Beeston is situated rises 20 to 30 feet above the flat. Gravel pits at Beeston show 10 feet or more of stratified gravel and sand, consisting mainly of quartzite pebbles, with many flints; the bedding of the gravel is much disturbed towards the top of the sections, but becomes more regular below. The gravel capping the spur near the confluence of the Leen, west of Lenton, should probably be associated with this series, though coloured as Glacial Gravel on the map because of its relation to gravels classed as Glacial higher up the Leen valley.

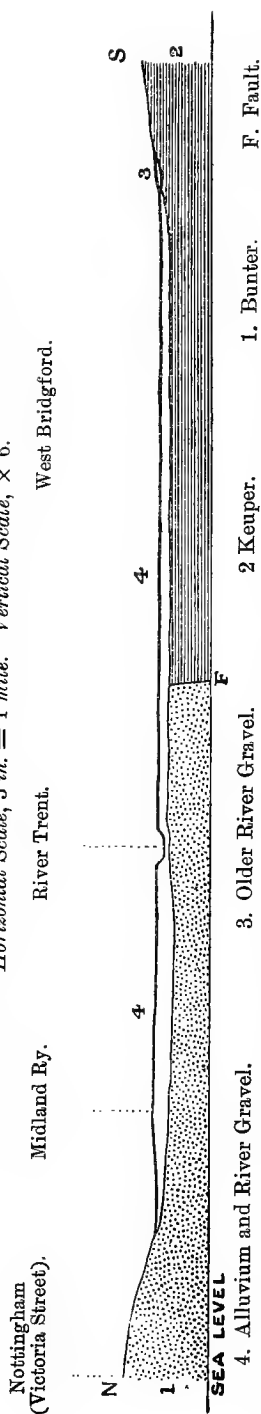
Below Nottingham, the Older Gravels set in on the south side of the Trent flat at West Bridgford and extends in a broken strip for $3\frac{1}{2}$ miles to Radcliffe-on-Trent, where they are cut out by the swinging back of the river to the southern bluffs. Between Gamston and Radcliffe the gravels now cap a slight ridge, owing to the unprotected Keuper Marl to the south having been denuded to a lower level, though originally the shingle probably formed a terrace abutting against a rising slope of the Marl. In pits at Gamston a thickness of 5 to 8 feet of sandy gravel is revealed, much contorted and mixed with loam at the top; the pebbles, mostly rather small, but with a few ranging up to a foot or more in diameter, are chiefly the usual Bunter quartzites, with some flints and cherts.¹

Below Radcliffe, the Trent valley becomes somewhat narrower and more sharply defined, maintaining this character up to the eastern limits of our area, and in this stretch the river-gravels appear all to belong to the newer set. But in the neighbourhood of Newark, five or six miles lower down the valley, the high bluffs of Keuper Marl disappear on the eastern side and are replaced by a broad terrace of gravel which swings away eastward across the low watershed dividing the Witham drainage from that of the Trent. From the distribution of similar gravel over the low ground between Newark and Lincoln, it has been deduced² that these

¹ A section of the gravels at Gamston has been described and figured by Mr. Deeley, *op. cit.*, *Quart. Journ. Geol. Soc.*, vol. xlii., p. 471 and Fig. 4.

² A. J. Jukes-Browne, 'On the relative Ages of certain River-valleys in Lincolnshire,' *Quart. Journ. Geol. Soc.*, vol. xxxix., 1883, pp. 596-610; and in 'Geology of S.W. Lincolnshire,' &c., *Mem. Geol. Surv.*, 1885, p. 90

FIG. 9.—SECTION ACROSS THE TRENT VALLEY FROM NOTTINGHAM TO WEST BRIDGFORD.

Horizontal Scale, 3 in. = 1 mile. Vertical Scale, $\times 6$.

gravels indicate a stage when the Trent flowed eastward from Newark to the Wash through the gap in the Oolite escarpment at Lincoln, instead of, as now, northward to the Humber. The Older Gravels of our map appear to be of the same age as the Newark terrace.

THE NEWER GRAVELS.

The gravels which cover the present floor of the Trent valley, though newer than the series above-described, appear still for the most part to be of considerable antiquity, and to denote a much more powerful river than that of to-day. Since their accumulation there has been a slight widening of the valley in places but hardly any deepening. The gravels are spread over it from side to side beneath the recent alluvium, and it is evident from the depth at which the Triassic strata have been reached in borings on different parts of the flat that the floor on which the river-deposits rest is fairly even and regular. At Nottingham, borings and excavations have been sufficiently numerous to enable us to draw the section across the river-flat shown in Fig. 9. In this transverse section the solid floor shows a very slight gradient to its deepest portion which lies some 300 yds. northward of the present river-bed, and there is no indication of any hidden trench or of the deeper erosion that we should expect to find if this portion of the river had ever attained a lower base-level. Nevertheless, there is evidence in the Trent valley below Newark that the land stood somewhat higher above sea-level than at present when the valley-gravels were deposited.

In its present enfeebled state the river wanders to and fro among its ancient gravel bars without sufficient energy to clear away all the detritus brought down to the flat by its tributaries. Therefore, since the gravels were deposited the general tendency has been toward a levelling up of inequalities by the deposition of loam,

sand and clay ; but otherwise, this part of the valley has undergone little alteration since it was swept by the torrential floods that spread pebbly detritus over the whole breadth of its floor. Where a broad trunk-valley of low gradient has steeper tributaries subject to seasonal floods, there is always a tendency for more detritus to be carried into the main valley than can be discharged from it ; and extensive river-flats are produced, on which the overloaded trunk-stream generally splits into many branches with constantly varying channels. All the features exhibited by the gravel-flats of the Trent indicate that the deposits mainly represent the overburden of ancient floods, channelled, and in places rearranged, during the later less vigorous phase of the river.

Even in our own days the river occasionally emulates its former activity, overcoming all artificial control, and rising in broad floods that temporarily submerge a large proportion of the flat. A well-remembered instance occurred 35 years ago, when the valley at Nottingham was for a short time in the state shown by the photograph reproduced as the frontispiece to this volume (Plate I), the flood in this case exactly marking out the extent of the river-flat.

The antiquity of some of the river-gravels is proved by their containing the remains of extinct Pleistocene mammalia. Several molars of mammoth have been found in the gravel or alluvium of the flat within the limits of our map (for details see 'Newark and Nottingham' memoir, p. 80),¹ but under conditions which do not enable us to determine whether they properly belong to the deposits or have been derived from the wastage of some pre-existing bed. There can be no doubt, however, as to the contemporaneity of some of the mammalian remains found in or on terraces of the Older Gravel in the Trent basin not far beyond the area of the map. Thus, at Allenton, near the junction of the Trent and Derwent, 3 miles west of our western boundary, the bones of hippopotamus, rhinoceros and elephant were excavated from the inner edge of a gravel terrace rising 15 to 20 feet above the alluvial flat ;² while elephant, rhinoceros, &c., have been found at several localities in the valley of the Soar.³ The Older Gravels are therefore distinctly Pleistocene, and it is further probable that a large part of the slightly later gravels on the floor of the valley are of sufficient antiquity to fall within the limits of the same epoch—limits which at the best are ill-defined.

The newer River Gravel is dug in most parts of the valley for local purposes, so that small sections are numerous ; but the best exposure in our area is afforded by the ballast-pits of the Great

¹ It is necessary here to mention that the specimen in the Nottingham Museum labelled as from "alluvial sand in St. Michael Street, Nottingham," and referred to in the above-mentioned memoir, was examined lately by Mr. E. T. Newton, F.R.S., who informs us that he found it to be the tooth of a recent Indian elephant.

² 'Discovery of Mammalian Remains in the Old River-gravels of the Derwent near Derby,' by H. H. Arnold-Bemrose and R. M. Deeley, *Quart. Journ. Geol. Soc.*, vol. lii., 1896, pp. 497-510.

³ 'The Melton Mowbray District,' &c., *Mem. Geol. Surv.*, 1909, p. 86 ; and 'The Country near Leicester,' *ibid.*, 1903, p. 56.

Northern Railway at Netherfield, showing 12 ft. of current-bedded gravel and sand, overlain in places by 2 to 4 ft. of pebbly loam.¹

The thickness of the river-deposits on the valley-floor has been proved by many borings, from which we select the following as illustrations:—*Thurgarton boring (just beyond the NE corner of the map), 21 ft. ; *Gunthorpe Bridge, 20 ft. ; *Burton Joyce water-works, 22 $\frac{3}{4}$ ft. ; *Colwick Sewage pumping-station, 24 ft. ; Nottingham, East Croft, Corporation yard, 28 ft. ; *Nottingham, Midland Goods Station boring, 27 $\frac{1}{2}$ ft. ; *Nottingham, Suspension bridge (several borings), 8 ft. to 18 ft. ; *West Bridgford, wells near canal, 18 ft. ; *Clifton Colliery, 25 ft. ; *Highfield Park boring, 22 ft. ; *Chilwell boring, 16 ft. ; †Sawley, three borings, 23 $\frac{1}{2}$ to 26 ft. Further details respecting the borings marked * will be found in the memoir on 'The Country between Newark and Nottingham,' and of those marked † in the memoir on 'The Country between Derby, &c. and Loughborough.'

ALLUVIUM.

The alluvial deposits of the Trent valley later than the flood-gravels have tended, as already mentioned, to level up the low undulations between the gravelly belts and spits. They consist mainly of the finer sediments brought down by the tributary streams from their steep upper reaches, and therefore vary according to the character of the rocks from which they have been washed. The Erewash has contributed grey silty clay, derived, like the narrow alluvium of its own valley, from the Coal Measures ; the Leen has yielded clayey loam, derived from the Permian and Bunter ; and the numerous small streams coming in on both sides from the Keuper country have deposited reddish-brown loamy clay where their current is checked on reaching the main valley-flat. These sediments are usually several feet thick around the mouths of the respective tributaries, and spread outward in broad fans which thin out gradually above the gravel. In such parts of the flat as were sheltered from these clayey sediments by gravel-bars, there have been local accumulations of stiff grey mud, containing much vegetable matter and thin seams of peat, which have filled up old swampy hollows. As a result of these variable local conditions there is, of course, much diversity in the composition of the soil and subsoil of the Trent flats.

Near the northern edge of the flats east of Nottingham, peat has been found in several excavations between Sneinton and Colwick, ranging in thickness from 2 to 4 ft. and usually covered by red clay or loam from 3 to 10 ft. thick. It is probable that this peat and the overlying deposits have filled up an old branch-channel of the river. There are, no doubt, many such buried channels in different parts of the flat.

The character of the alluvium of the tributary valleys has been indicated above, and hardly needs further description as the details are available for reference in our previous 'sheet' memoirs. The red loamy clay derived from the Keuper sometimes reaches a

¹ 'The Country between Newark and Nottingham, p. 82.

thickness of 8 or 10 ft. in the small alluvial flats of the deep valleys or 'dumbles' east of Nottingham. At its base there is often an irregular gravelly bed, associated with sandy and muddy seams containing land and fresh-water shells, plant-remains and mammalian bones. A collection made from a deposit of this kind in the banks of the Cocker Beck below Lambley proved that it was not of earlier date than Neolithic, as the bones were those of domesticated animals (horse, ox, sheep or goat, and pig), along with a human femur, flint flakes and charcoal.¹

Besides the alluvium of its streams, the Keuper lowland south of the Trent contains numerous broad depressions which have formed bogs or swamps until artificially drained, and are still subject to floods in seasons of excessive rainfall. Such tracts occur most frequently along the outcrop of the upper gypsiferous portion of the Keuper Marl, where their presence may be due partly to the removal of gypsum in solution and partly to the more speedy disintegration of the marl associated with the gypsum. They are floored with thin deposits of fresh-water origin, generally including much dark loamy clay washed from the Lias and Rhætic, with some sand and gravel derived from the Glacial drifts, and patches of white shell-marl denoting temporary lakelets. These tracts often possess peaty-loam soils and subsoils, but there is usually very little peat in their deposits beneath the surface.

The largest area of alluvium of this character within the map is that which forms the Moors south-west of Ruddington; smaller tracts occur between Gamston and Edwalton; between Tollerton and the Grantham Canal; east of Cropwell Bishop; and north of Bingham. The land and fresh-water shells collected from the deposits are all of recent species.²

¹ 'The Country between Newark and Nottingham,' *Mem. Geol. Surv.*, 1908, pp. 86-7.

² For lists from Gotham Moor, &c., see C. T. Musson, 'Subfossil Shell-deposits in Nottinghamshire,' *Journ. of Conchology*, vol. iv., p. 162; and lists from other localities are given in 'The Country between Newark and Nottingham,' *Mem. Geol. Surv.*, 1908, pp. 87-8.

CHAPTER VIII.

SUPPLEMENTARY NOTES FOR STUDENTS.

INTRODUCTION.

In the memoirs explanatory of the numbered series of the Geological Survey maps it is customary in the concluding chapter to deal with the economic geology of the district. But as this has already been done in the 'sheet' memoirs for the area of the 'Nottingham District' map, and as the map and present memoir are intended primarily to serve the requirements of Nottingham as an educational centre, we think it advisable in this case to substitute a chapter for the use of the geological student, giving an epitome of the local geological features which afford good elementary illustrations of structure and of the meaning attached to the commoner geological terms.

Similarly, as an aid to the advanced student in selecting a field for new work, we include in the chapter some suggestions for further research, since our own work has necessarily brought to our notice many problems requiring closer and more prolonged investigation.

STRUCTURAL PHENOMENA.

The *dip* of stratification in all the rocks of the district newer than the Coal Measures is usually at so low an angle as to be hardly perceptible in single sections unless the exposure is of large size; its direction and value will, however, be readily appreciated on noting the surface-level of any particular stratum in different parts of its outcrop, from its relationship to the contour lines on the map. The base of the Waterstones, the base of the Keuper Marl, and the Rhætic Beds afford good examples for the practice of this method. Though so feeble, the effect of the dip is well brought out by the *strike* of the escarpments and outcrops of the different formations, *e.g.*, those of the Magnesian Limestone, Bunter Pebble Beds, and Keuper, in the north-central part of the map, and of the Rhætic and Lias at the south-eastern corner. In clear exposures, the *bedding-planes* are usually numerous, readily distinguishable, and 'true' (*i.e.*, approximately parallel to the plane of the whole formation) in most of the 'solid' rocks, but in some of the Carboniferous sandstones and in the Bunter *cross-bedding* or *current-bedding* is very prevalent (*see* Plate IV, p. 31). *Contorted bedding* is rare in the district, though examples on a small scale may be seen in the Keuper Marl in Lambley Dumble and a few other places (marked by twisted arrows on the map), and in the vicinity of some of the faults in the Coal Measures. The *anticlinal* and *synclinal folds* of the Coal Measures (pp. 20-1) are too broad and open to be recognized as such except by the examination of a wide tract of country.

Faults are numerous in the Coal Measures, but are much rarer in the overlying formations. The Permian and Trias frequently lie unfractured across the faulted Coal Measures, thus proving that many of the faults existed in their present state before the Permian strata were deposited (p. 19). The faults of the Coal Measures

are principally discovered in mine-workings; indeed there is often no other evidence of their existence, though sometimes their surface position is indicated by displacements of the outcrops of sandstones or other recognizable bands. Occasionally, a fault is clearly revealed in section, as in the instance shown in Plate II., p. 21, from a photograph of a clay-pit near Giltbrook, taken in 1893. This particular section is now obliterated, but recently (1908) another clay-pit in the Coal Measures at Ilkeston has revealed a small fault with equal clearness. Again, in the Keuper between Nottingham and Netherfield the two small faults indicated on the map are well seen in the deep cutting on the north side of the Great Northern railway. In the majority of cases, however, the faults shown on a geological map are deduced from less evident but still quite obvious interruptions in the course of the beds. The group of important east-and-west faults at the southern margin of the coal-field, if followed along their course, will afford insight into the nature of the evidence (p. 20).

Unconformity or *unconformability* is strikingly illustrated by the relations of the newer rocks to the underlying Coal Measures (see Chap. II., pp. 21-3, and Fig. 3). There are excellent sections revealing this unconformity in the Great Northern railway cuttings around Kimberley Station, where the breccia at the base of the Permian is seen to rest on the inclined Coal Measures. *Unconformable overlap* or *overstep* is exemplified by the relations of the Triassic to the Carboniferous rocks along the southern margin of the coal-field, where the Bunter oversteps, in succession, the Middle Coal Measures, the Lower Coal Measures and the Millstone Grit. *Conformable overlap* may be represented by the relations of the Bunter to the Permian, if we accept the view that the two formations are conformable and that the present southward limits of the Permian coincide approximately to its original bounds, while the Bunter was deposited over a wider area. If, however, we adopt the alternative supposition, that the Permian was eroded and reduced in extent before the Bunter was laid down, the case is one of unconformable overlap.

The leading features in the physiographical or surface expression of geological structure, with examples of *escarpment*, *dip-slope*, *longitudinal* and *transverse valley*, &c., have been touched upon in the introductory chapter (I.) of this memoir, and do not require recapitulation.

ILLUSTRATIVE SECTIONS OF THE STRATA.

It may be useful briefly to summarize the local opportunities for elementary study afforded by the several formations in the order of their upward succession. Fuller information with regard to many of the sections referred to may be obtained from foregoing chapters.

The MILLSTONE GRIT is best exposed in the old quarry indicated by a dip-arrow on the map, 300 to 400 yards east of Stanton-by-Dale.

The best sections of the COAL MEASURES are of course afforded by the colliery shafts and workings, but the strata are most conveniently exposed for examination in open clay-pits around Ilkeston, Heanor and Eastwood (p. 16).

The PERMIAN BASEMENT BRECCIA, as above-mentioned, is seen in section in the railway cuttings at Kimberley. The extension of the same cuttings eastward on the Great Northern railway between Kimberley and Hemphill affords a comprehensive section across the MAGNESIAN LIMESTONE of the district, from its base nearly to its summit, revealing the marked distinction between the lower portion or *Marl Slates* and the *Dolomitic Limestone* above. A portion of this fine section is illustrated in Plate III., p. 26.

The MAGNESIAN LIMESTONE may also be studied to advantage in the stone-quarries at Bulwell and in the railway cuttings between Bulwell and Hucknall Torkard. The PERMIAN MARL, up to its junction with the Bunter, is best exposed in the brickyard pits between Bulwell and Cinderhill.

Opportunities for examining the BUNTER formation are numerous in most parts of its outcrop. The lower subdivision or LOWER MOTTLED SANDSTONE is best seen in the big pits from which sand is dug for moulding, building, or ballast, among which are those at Hemphill (illustrated in Plate IV., p. 31), Lenton, Bobbers Mill, and at the cross-roads south of Basford Hall. For the PEBBLE BEDS, we may take the crags of Nottingham Castle (Plate V. p. 32) as a typical example; they are likewise exposed in street-cuttings and other excavations on most of the steep slopes in the city, in railway and road cuttings in every part of the outcrop, and in natural crags around Bestwood Park, Stapleford and Bramcote Hills and other places, as well as in numerous pits, among which those near Dale are of especial interest (p. 21).

The best sections of the KEUPER are those of an artificial character, and of these there is fortunately no lack. The base of the Keuper was recently shown very clearly in an excavation at Sneinton, illustrated in Fig. 6, p. 35, which is probably by this time obliterated. The WATERSTONES are accessible in natural sections in the deep stream-cut 'dumbles' or ravines near Burton Joyce, Lambley and other places, and in shallow road-cuttings at numerous points, *e.g.*, Gonalston, Gedling, Carlton, Red Hill near Arnold, &c.; but the best exposures are in the railway cuttings around the eastern suburbs of Nottingham, particularly in the neighbourhood of Colwick, Thorneywood, and Sherwood Station. The KEUPER MARL, in its lower portion, is conveniently displayed in the deep pits of the brickyards along the Mapperley Plains escarpment and at Carlton and Thorneywood, while higher horizons are represented in brickyard sections near West Bridgford (Plate VI., p. 40) and Radcliffe-on-Trent. The gypsiferous belt near the top of the red marls may be studied in the gypsum pits at Cropwell Bishop; and the *Tea-green Marl* at the top of the Keuper, in a small brickyard at the foot of the Rhætic escarpment $\frac{1}{2}$ mile south of Cotgrave.

The RHÆTIC BEDS are scantily exposed in the district, the best section being that of a small quarry and cutting alongside the Grantham Canal at Blue Hill, $\frac{3}{4}$ mile south of Cropwell Bishop (see Fig. 7 and p. 44).

Natural exposures are rare in the LOWER LIAS country, but the deficiency, in so far as the lower part of the formation is concerned,

is partly compensated by the pits from which the *Hydraulic Limestones* are quarried $\frac{1}{2}$ mile north-east of Owthorpe. There are also several old but not yet obliterated quarries in the same series, *e.g.*, that by the side of the canal at the Devil's Elbow.

The GLACIAL DEPOSITS present few opportunities for investigation. BOULDER CLAY, resting on a glaciated rock-surface, was formerly exposed in the railway-cutting at the approaches to the Stanton tunnel (see Fig. 8, p. 53), but the section is now obscured. Ponds and similar shallow excavations in the boulder-clay tracts will usually suffice to show its main characteristics. The GLACIAL GRAVELS are generally better displayed, being quarried on a small scale in many localities, as at Long Hill near Hucknall, The Warren near Bestwood Lodge, Highbury Vale near Bulwell, &c. The OLDER RIVER GRAVEL is extensively dug at Beeston and Gamston.

Of the later superficial deposits, the RIVER GRAVEL of the Trent is often exposed in small temporary excavations around the towns and villages, the most extensive section being that of the Great Northern Railway ballast-pits at Netherfield. The banks of the smaller streams generally show sections of their ALLUVIUM at intervals, a good example being afforded by the Cocker Beck; and the variable character of the alluvium of the Trent valley may be seen in the artificial trenches by which the flats are drained, especially in those of the Nottingham Sewage Farm between Stoke Bardolph and Gunthorpe.

SUGGESTIONS FOR FURTHER RESEARCH.

While the best results are always likely to be attained by the student who follows his own bent in research, and discovers for himself a fresh standpoint from which to work, it will not be amiss that we should briefly indicate the principal questions regarding which we found the information still incomplete, and were unable, under the conditions of our survey, adequately to supply the deficiency.

CARBONIFEROUS. The presence of bands of marine origin occurring in the Middle and Lower Coal Measures has been mentioned in Chapter II (pp. 17-18); but the number of these bands and their fossil-contents are imperfectly known. The close investigation of bands of this character in new sinkings or other sections of the Coal Measures is highly desirable.

There is also still much to be done in working out the general palaeontology of the Coal Measures. The rich additions to the fauna recently made by Dr. L. Moysey (p. 16) show what may be achieved by careful collecting; the zonal succession of the commoner lamellibranchs is as yet only partly known; and the fossil flora requires further elucidation.

The petrology of the Carboniferous sediments of the district is a practically untouched field. An investigation of the minute composition of the commoner clays, shales and sandstones might yield results of interest; and an examination of the peculiar 'Espley rock' (p. 18) and associated beds penetrated in the borings into the concealed Upper Coal Measures should be well worth the time spent upon it. The presence of an igneous rock among the Coal

Measures in the Owthorpe boring (p. 23) requires further explanation, which may be obtainable in any further boring in this quarter.

In view of a possible unconformity, the relation of the Upper Coal Measures to the Middle Coal Measures is also a matter deserving close attention when the opportunity is presented by underground exploration.

On the chemical side, there is need for further systematic study and analysis of the Coal Measures and their coals; and similar work on any of the other formations in the map would furnish useful data which are still for the most part lacking.

PERMIAN. Much good work has been done in the past by the local geologists, especially by Wilson and Shipman, on the Permian strata of the district, but there are still possibilities for further research. Little is known respecting the manner in which the formation ends off southward, as the available sections in this quarter are poor and scanty. Any excavations that may be made along this margin should be carefully investigated, in order that the meaning of the Triassic overlap or overstep may be better understood (p. 24). The oft-debated question whether the Trias is conformable or unconformable to the Permian is still unsettled and might be elucidated by new sections at their junction. The relationship between faults in the Coal Measures and minor disturbances of bedding in the overlying Permian also deserves further study.

Fossils in the Permian are neither sufficiently abundant nor well-preserved to attract the collector; but, for this reason, such as do occur are the better worth noting. The presence of fragmentary plant-remains in the 'Marl Slate' subdivision suggests the possibility of determinable specimens being obtained from these beds, but no species have yet been recorded.

TRIAS. The problems of the Trias are mainly those bearing on its mode of origin and the source of its constituents. Though generally devoid of fossils, the chance discovery of numerous fish-remains in the Waterstones by Wilson (p. 37), and quite recently, of some fragmentary plants near the top of the Bunter by Mr. R. D. Vernon, prove that palæontological quest is not quite hopeless.¹ The relations of the Keuper division to the Bunter have led to much discussion in the past, and all good exposures of the junction deserve careful notice, though it is doubtful whether any new features will be observed. The source of the Bunter pebbles is another subject on which there has been a prolonged discussion, with divergence of opinion (p. 30); good work might be done by making a systematic study of these pebbles throughout the district, noting their average size, relative abundance and composition in typical exposures all along the outcrop, and by examining them in sufficient numbers to yield a percentage proportion of all the varieties present in different places. While much attention has been given to the rarer kinds, there seems to have been no serious attempt to deal with the commoner sorts, or to calculate their proportional abundance.

¹ The recent discoveries of Dr. Swinnerton, mentioned in the footnote on p. 38, give an opportune incentive to further search.

The microscopic lithology of the Triassic and Permian sediments, like that of the Coal Measures, is as yet almost untouched in this district. The determination of the minute constituents (both the common and the rare minerals) and their characteristics would be likely to throw light upon the origin of the formations. The relations of the Trias to the uneven surface of Carboniferous rocks at the southern end of the coal-field are, again, worthy of further study; while any new sections at the top of the Keuper, showing its junction with the overlying Rhætic, should be closely examined for evidence of the slight unconformity which has been supposed by some observers to occur at this horizon.

The composition and fossil-contents of the Rhætic deserve attention whenever the opportunity is afforded, as good exposures of this series are rare.

The presence of abundant crystalline gypsum in some parts of the Trias furnishes another subject in which further research would be useful; as, likewise, does the question, largely chemical, whether the colour of the Tea-green Marl is original or secondary. Other analogous problems will suggest themselves to the student who may devote himself to the investigation of the Triassic sediments in their chemical aspect.

LIAS. Fossils are fairly numerous in the Nottinghamshire Lias, and the palæontological lists could undoubtedly be amplified by systematic collecting. The beds have long been famous for their fish and saurian remains, but these are not easily dealt with by the private collector. The quarries near Owthorpe afford sections actually within the map, while the exposures at Barnstone to the east and Barrow to the south, in approximately the same part of the formation, offer still better opportunities. The prolonged examination of such sections, bed by bed, and the tabulation of all the species procurable from each could not fail to add considerably to our knowledge of the fauna, which at present is too much dependent upon the more conspicuous fossils obtained by the workmen. The modern refinements in palæontology have, however, made it increasingly difficult for the collector to obtain exact determinations of his specimens; but he would soon qualify himself, in the course of his work, personally to identify the commoner species, leaving a residue of the rarer forms only to be submitted to the specialist.

GLACIAL DEPOSITS. The scanty development of the Glacial drift over the greater part of the district in itself constitutes a problem which is not yet solved (p. 53). It is still doubtful how much of the present valley-system was in existence before the glaciation and how much has been since excavated.

The drifts which have been stated to occur within the valleys (p. 55) are of dubious character; therefore it is desirable that all sections in the floors of the main valleys should be inspected and the character of the superficial deposits within them carefully noted. It is often very difficult to distinguish between Glacial deposits in their original position and the same material re-arranged at a later date in a new position by down-wash, &c., and this should be always borne in mind in studying the valley-deposits. The transported boulders that occur in the drift-clays and gravels require to

be sampled, measured and noted, particularly when they present characters which might enable their source to be traced. The question whether the deposits of the district represent several epochs of glaciation separated by intervals of warm 'interglacial' conditions, as urged by some observers, or whether they may be interpreted as the product of a single glacial epoch with varying phases, is still undecided and awaits further evidence (p. 54). In short, the geological history of this part of the country during Glacial times is as yet imperfectly understood.

POST-GLACIAL DEPOSITS. The river-gravels and other alluvial deposits of the Trent valley cover a range of time extending from the close of the Glacial period to the present day. The work of unravelling the successive stages is, however, not easy and has been only in part accomplished. Presumably the older gravels are likely to date back to palæolithic times, but so far as we are aware no undoubted palæolithic implement or other evidence of early man has yet been found in them. A thorough search for such evidence is highly desirable. The bones of extinct mammals, *e.g.*, the mammoth, are occasionally found in these deposits and are always deserving of particular note.

The fresh-water shells, plant-remains, bones of animals, &c., contained in the later alluvial deposits of many of the valleys and old swamp-hollows afford scope for systematic investigation and comparison with the existing fauna and flora. The collection obtained from an alluvial deposit of the Cocker Beck mentioned in the preceding chapter (p. 61), may be cited as an illustration of the results to be expected from research of this kind.

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SECTIONS OF SHAFTS AND BORINGS SHEWING THE EXTENSION OF THE COALFIELD BENEATH THE PERMIAN & TRIAS FORMATIONS

Scale One Inch = 500 Feet.

By W. GIBSON D.Sc.

THURGARTON BORING

57.0D.
KEUPER MARL 139ft
WATERSTONES 150ft
BUNTER (494ft)

LINBY COLLIERY

290.0D.

PERMIAN
Coal 2ft 2in
Coal 1ft 11in.
Coal 1ft 3in.
Coal 1ft 3in.
Coal 2ft 8in.
TOP HARD COAL 4ft 7in.

WOOD COLLIERY

228.0D.

BUNTER
PERMIAN
Coal 1ft 11in.
Coal 2ft 10in.
Coal 2ft 10in.
Coal 2ft 10in.
TOP HARD COAL 6ft 6in.

GEDLING COLLIERY

185.0D.

KEUPER
BUNTER
PERMIAN
ETRURIA MARL GROUP
MARINE BED
Coal 2ft 10in.
MARINE BED
HIGH MAZES COAL 3ft 9in.
Coal 2ft 10in.
Coal 3ft 5in.
Coal 2ft 11in.
TOP HARD COAL 5ft 6in.

CLIFTON COLLIERY

80.0D.

BUNTER
TOP HARD COAL 5ft 11in.
WATERLOO COAL
DEEP SOFT COAL
DEEP HARD COAL
PIPER COAL

EDWALTON BORING

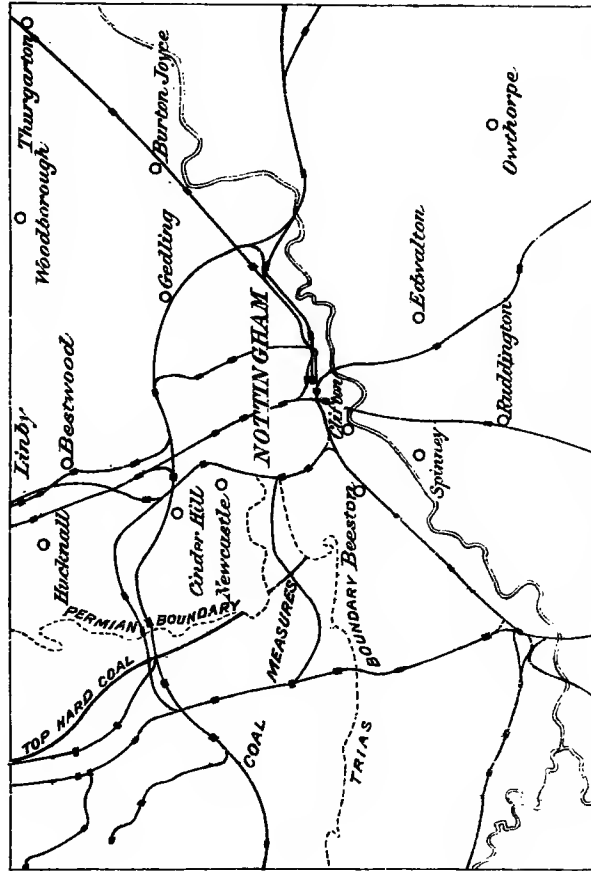
95.0D.

KEUPER MARL
KEUPER WATERSTONES
DUNSTON COAL
WATERLOO COAL
DEEP SOFT COAL
PIPER COAL
FURNACE (TUFTON) COAL
SILKSTONE COAL

RUDDINGTON BORING

100.0D.

KEUPER MARL
KEUPER WATERSTONES
BUNTER
WINGFIELD FLAGSTONES
NAUGHTON COAL 2ft 5in
ALTON COAL 3ft 4in
Base of Coal Measures
FIRST CRIT.



Scale 4 Miles to the Inch.

MIDLAND DISTRICT—*cont.*

SIX-INCH MAPS ON THE SCALE OF 6 INCHES = 1 MILE

(1 to 10560).

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40 NW, 40 NE (Notts. 32^a NE), 40 SW, 40 SE; 41 NW (Notts. 32 NW), 41 SW (Notts. 32 SW); 45 NW, 45 NE, 45 SW, 45 SE; 46 NW (Notts. 37 NW), 46 SW (Notts. 37 SW); 50 NW, 50 NE, 50 SW, 50 SE; 51 NW (Notts. 41 NW), 51 SW (Notts. 41 SW); 57 SW (Staffs. 41 SW), 57 SE; 58 SW (Leic. 9 SW); 60 NW (Staffs. 47^a NW), 60 NE (Leic. 15 NE), 60 SW (Leic. 15 SW), 60 SE (Leic. 15 SE); 61 NW (Leic. 16 NW); 63 NW (Staffs. 54 NW, Leic. 22 N.W.), 63 NE (Leic. 22 NE).

Leicestershire :—

9 SW (Derby. 58 SW); 15 NE (Derby. 60 NE), 15 SW (Derby. 60 SW), 15 SE (Derby. 60 SE); 16 NW (Derby. 61 NW), 16 NE, SW, SE; 22 NW (Derby. 63 NW, Staffs. 54 NW), 22 NE (Derby. 63 NE), 22 SE; 23 NW, NE, SW, SE; 29 NE; 31 NW, NE, SW, SE; 37 NW, NE.

Nottinghamshire :—

32 NW (Derby. 41 NW), 32 NE, 32 SW (Derby. 41 SW), 32 SE; 32^a NE (Derby. 40 NE); 37 NW (Derby. 46 NW.), 37 NE; 37 SW (Derby. 46 SW), 37 SE; 41 NW (Derby. 51 NW), 41 NE, 41 SW (Derby. 51 SW), 41 SE.

Staffordshire :—

3 SW, SE; 6 NE, SW, SE; 7 NW, NE, SW, SE.; 11 NW, NE, SW, SE; 12 NW, NE, SW, SE; 13 NW, SW, SE; 16 NE, SE; 17 NW, NE, SW, SE; 18 NW, NE, SW, SE; 19 NW, NE, SW, SE; 22 NE; 23 NW, NE; 24 NW, NE; 41 SW (Derby. 57 SW); 47^a NW (Derby. 60 NW); 54 NW (Derby. 63 NW, Leic. 22 NW).

Six-inch maps which are included in the one-inch New Series maps named above, but which do not contain any part of the Leicestershire and South Derbyshire and North Staffordshire Coalfields, are not published, but MS copies have been deposited in the Geological Survey Office, where they can be consulted, or copied, if desired, at the cost of draughtsmanship.

MIDLAND DISTRICT—*cont.*

MEMOIRS.

In addition to the Memoirs (Sheet-explanations) mentioned under the head of one-inch maps, District Memoirs on the North Staffordshire Coalfield (price 6s.), and Leicestershire and South Derbyshire Coalfield (price 6s.) have been published.

VERTICAL SECTIONS (scale 1 inch = 100 feet).

Price, 1s. 8d. each.

Sheet 86, Sections of Shafts, &c. in the Pottery Coalfield, North Staffordshire ; 1901.

Sheet 88, Sections of Shafts, &c. in the Southern part of the Derbyshire and Nottinghamshire Coalfield.

For publications relating to other parts of the United Kingdom, reference should be made to the Catalogue, price 6d., obtainable at all Agents.

